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**Towne**

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(54) **MAGNET-BASED ANTI-COGGING APPARATUSES AND SYSTEMS FOR APPLYING AN ANTI-COGGING TORQUE ON A ROTATING SHAFT**

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(60) Provisional application No. 61/403,547, filed on Sep. 18, 2010.

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**F16F 15/00** (2006.01)

(52) **U.S. Cl.**  
CPC ..... **F02B 75/06** (2013.01); **F16F 15/005** (2013.01); **Y10T 74/2101** (2015.01)

(58) **Field of Classification Search**  
CPC ..... F02B 75/06; F02B 75/20; B60W 10/06; B60W 10/08; F16F 15/264; F16F 15/265; H02K 21/24; H02K 1/2793  
USPC ..... 123/192.1, 192.2; 318/400.23; 310/156.35

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

1,312,585 A	8/1919	Shepherd	
1,899,431 A	2/1933	Woolson	
2,842,691 A *	7/1958	Pampliega	
		Tajadura .....	H02K 47/00 310/138

(Continued)

FOREIGN PATENT DOCUMENTS

DE	102010044716 A1	4/2011
EP	0175952 A2	4/1986

(Continued)

OTHER PUBLICATIONS

International Search Report for International Application No. PCT/US2012/055015 mailed Feb. 28, 2013.

(Continued)

*Primary Examiner* — Lindsay Low

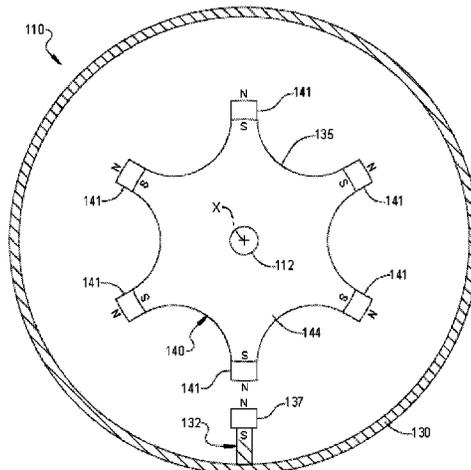
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(57) **ABSTRACT**

An anti-cogging apparatus includes a first support member, a second support member, a first set of magnets, and a second set of magnets. The first support member is configured to be connected to and rotate with a rotatable shaft. The second support member does not rotate and is configured not to move with the first support member. The first set of magnets is mounted on the first support member in an alternating polarity or a non-alternating polarity configuration. The second set of magnets is mounted on the second support member in an alternating polarity configuration or a non-alternating polarity configuration. The first set of magnets magnetically interacts with the second set of magnets to provide an anti-cogging torque on the rotatable shaft.

**42 Claims, 27 Drawing Sheets**



(56)

References Cited

U.S. PATENT DOCUMENTS

3,293,939	A	12/1966	Brown	
3,998,200	A	12/1976	Sudholt	
4,151,431	A	4/1979	Johnson	
4,779,454	A *	10/1988	Fitzner .....	F02P 7/067 123/149 D
4,858,044	A	8/1989	Crapo	
5,455,474	A	10/1995	Flynn	
5,572,962	A	11/1996	Riley	
6,054,788	A *	4/2000	Dombrovski .....	H02K 49/00 310/103
6,184,605	B1	2/2001	Kim	
6,246,561	B1	6/2001	Flynn	
6,946,938	B1	9/2005	Pedersen	
7,248,006	B2	7/2007	Bailey et al.	
7,265,471	B2	9/2007	Sprain	
7,327,061	B2	2/2008	Rogala	
7,342,623	B2	3/2008	Ishizaki	
7,479,722	B2	1/2009	Takeuchi et al.	
7,737,596	B2	6/2010	Boucher et al.	
8,232,690	B2 *	7/2012	Overstreet .....	H02K 7/075 310/15
8,701,615	B2	4/2014	Towne, III	
2003/0071530	A1	4/2003	Takahashi	
2003/0080641	A1	5/2003	Ando et al.	
2004/0212273	A1	10/2004	Gould	
2005/0029888	A1	2/2005	Inayama et al.	

2005/0275359	A1	12/2005	Takeuchi et al.
2006/0037595	A1	2/2006	Procknow
2007/0017464	A1	1/2007	Pflug et al.
2008/0174189	A1	7/2008	Boucher et al.
2012/0067317	A1	3/2012	Towne
2012/0074913	A1	3/2012	Finkle
2013/0270951	A1	10/2013	Semmer et al.
2014/0165775	A1	6/2014	Towne

FOREIGN PATENT DOCUMENTS

JP	S555453	A	1/1980
JP	S62242152	A	10/1987
JP	2011089477	A	5/2011
WO	WO 2008-089536		7/2008

OTHER PUBLICATIONS

Written Opinion of the International Searching Authority for International Application No. PCT/US2012/055015 mailed Feb. 28, 2013.

International Search Report and Written Opinion for PCT Application No. PCT/US2015/016681 mailed Jul. 10, 2015; 19 pages.

Search Report from European Application No. 12830936.6 dated Mar. 20, 2015; 5 pages.

Chinese Office Action dated Dec. 9, 2015 from corresponding CN Application No. 20128044242.X with English translation.

\* cited by examiner

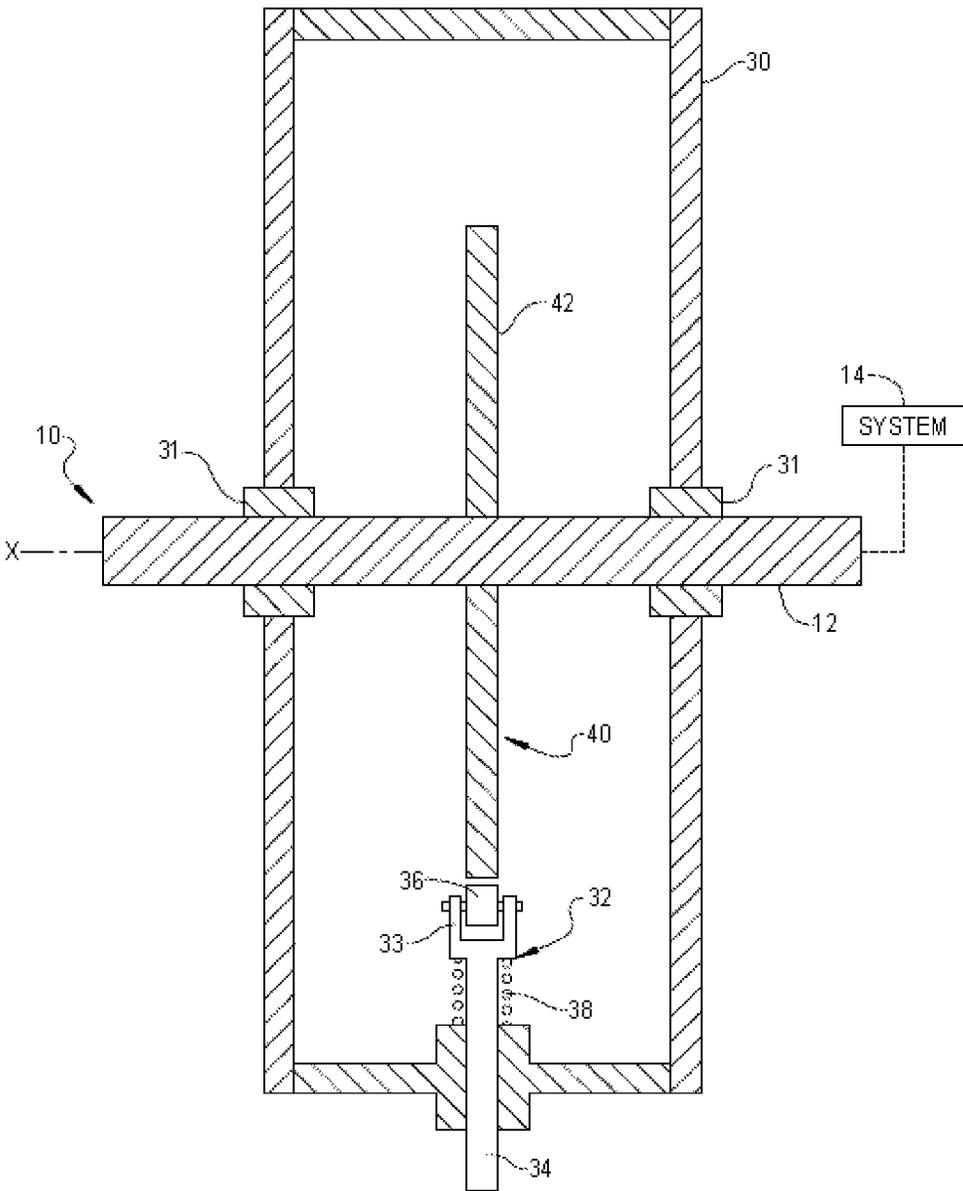


FIG. 1

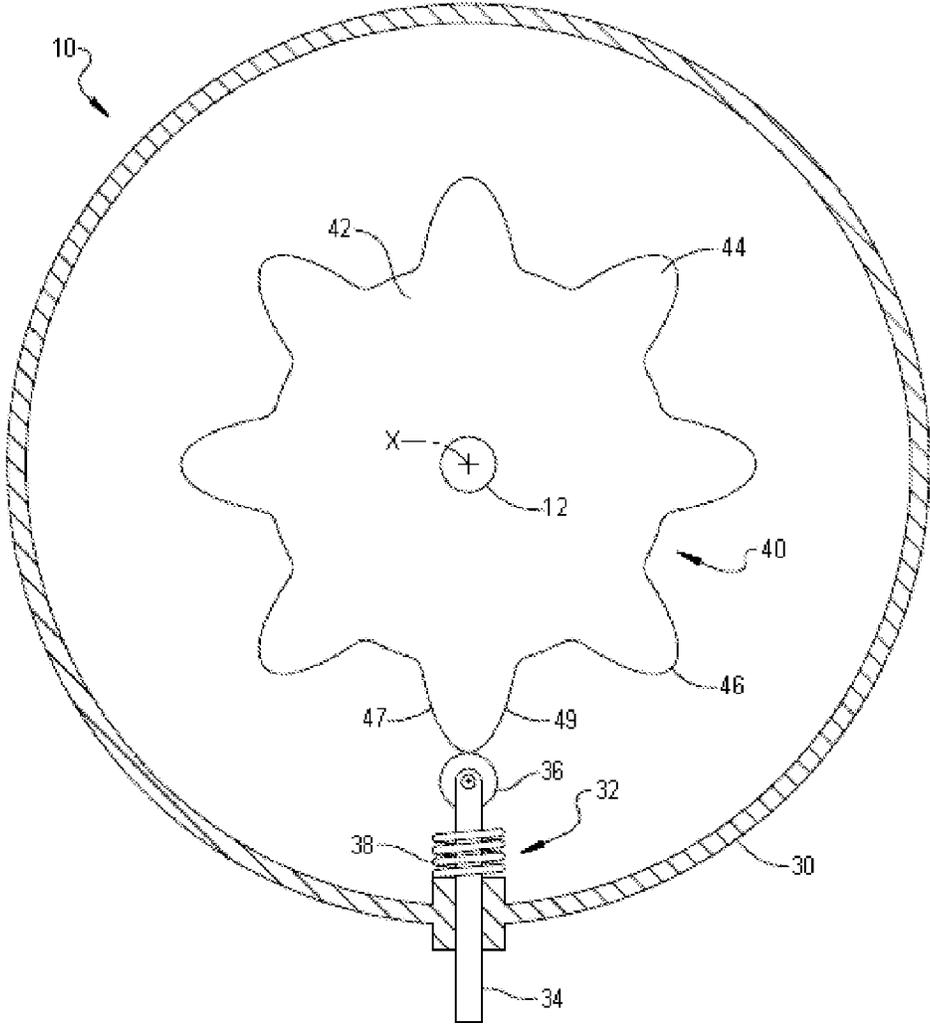


FIG. 2

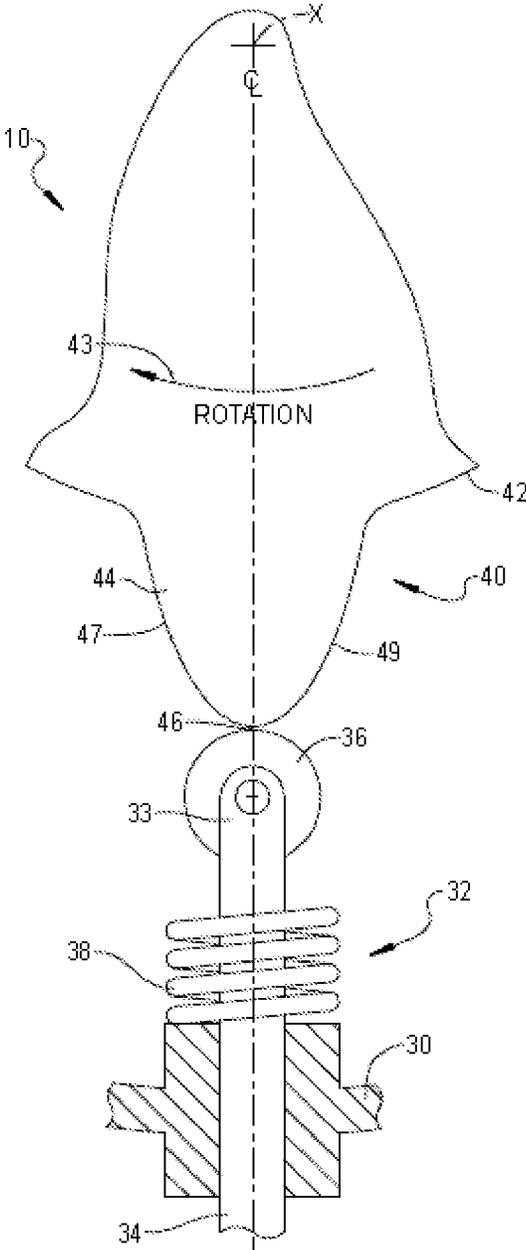


FIG. 3

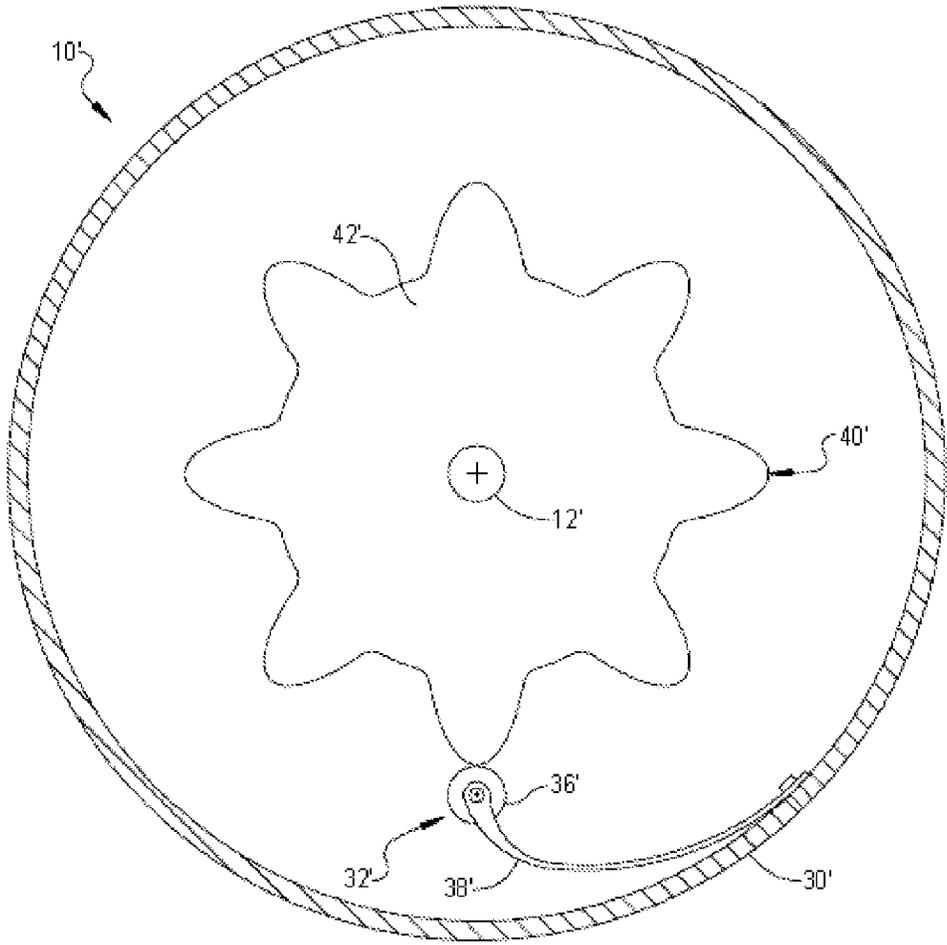


FIG. 4



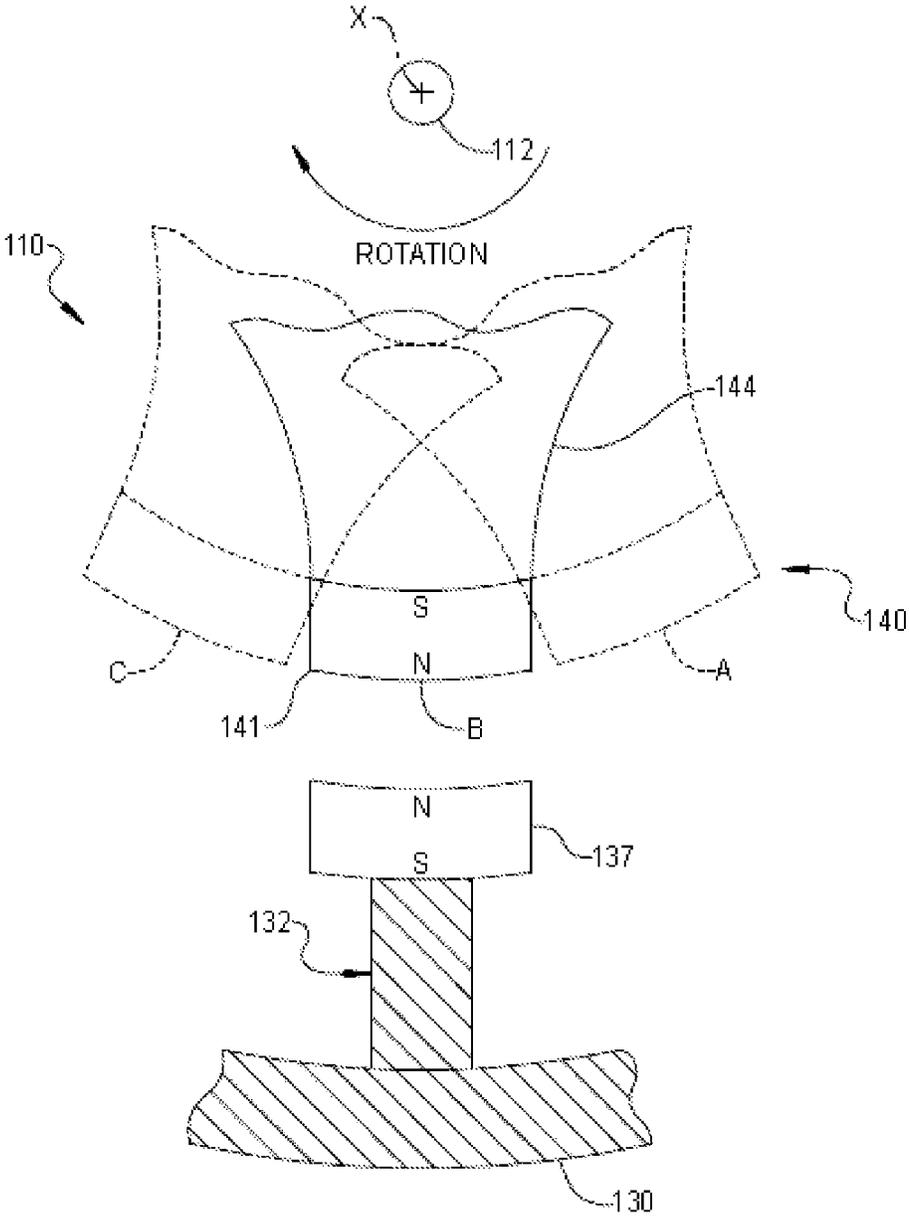


FIG. 6

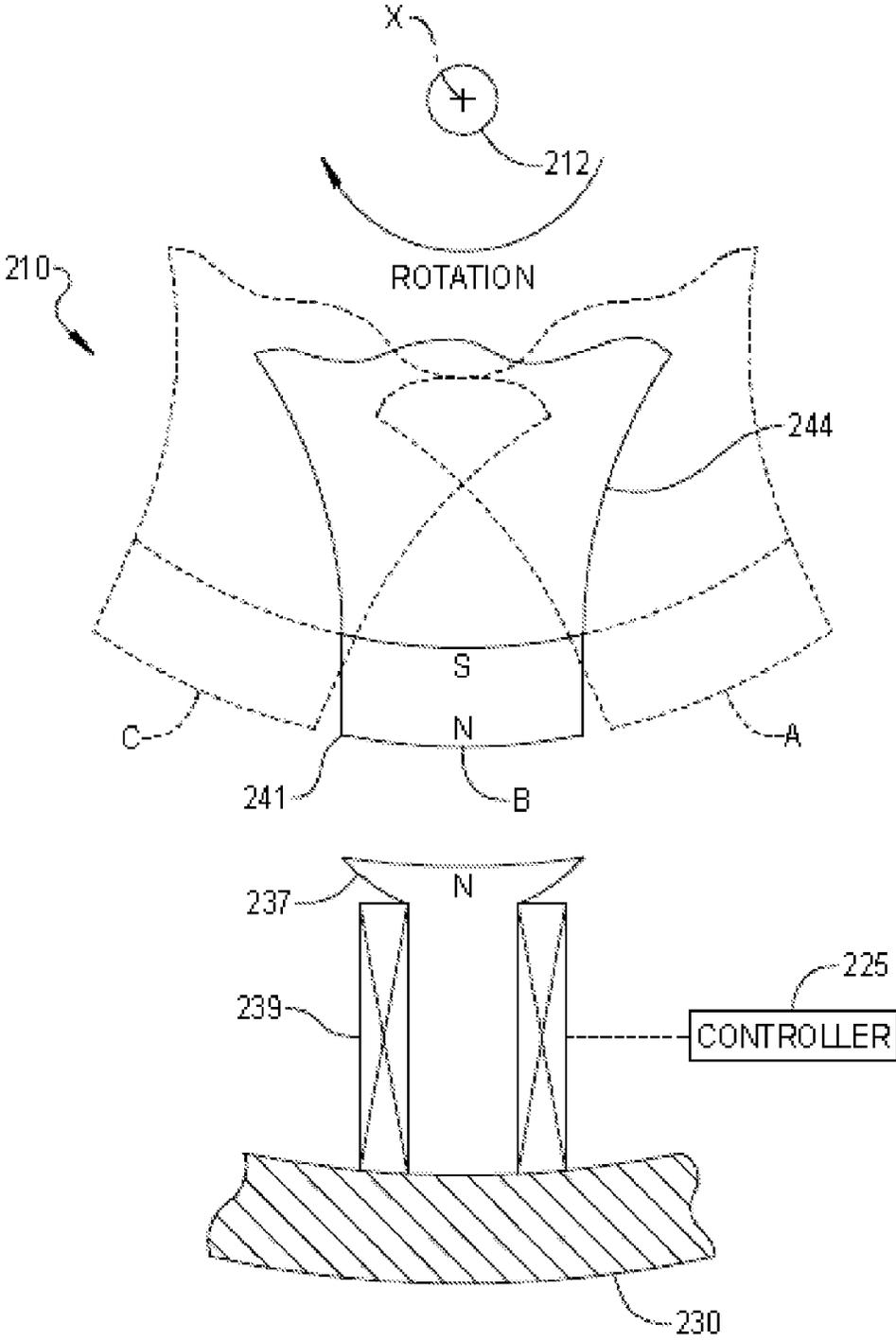


FIG. 7

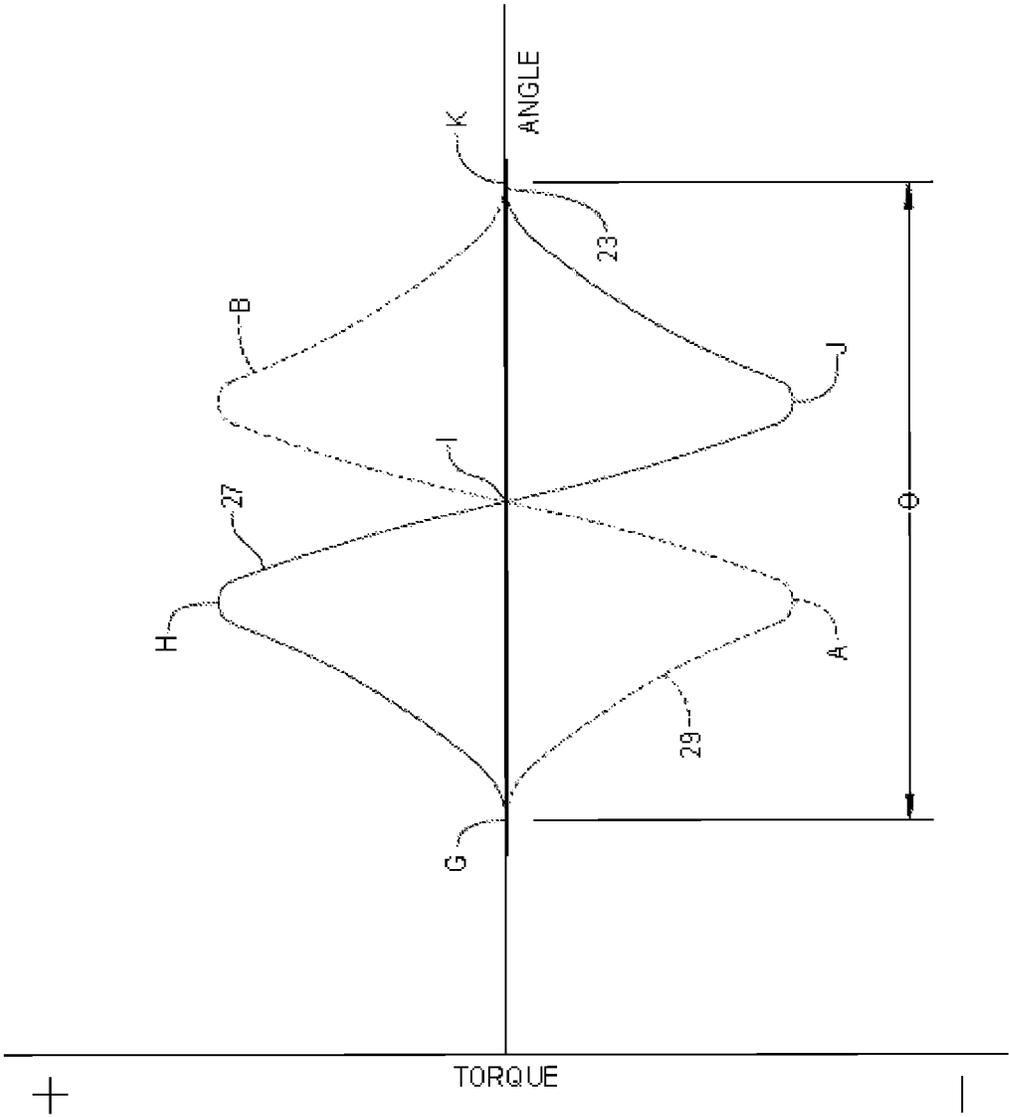


FIG. 8

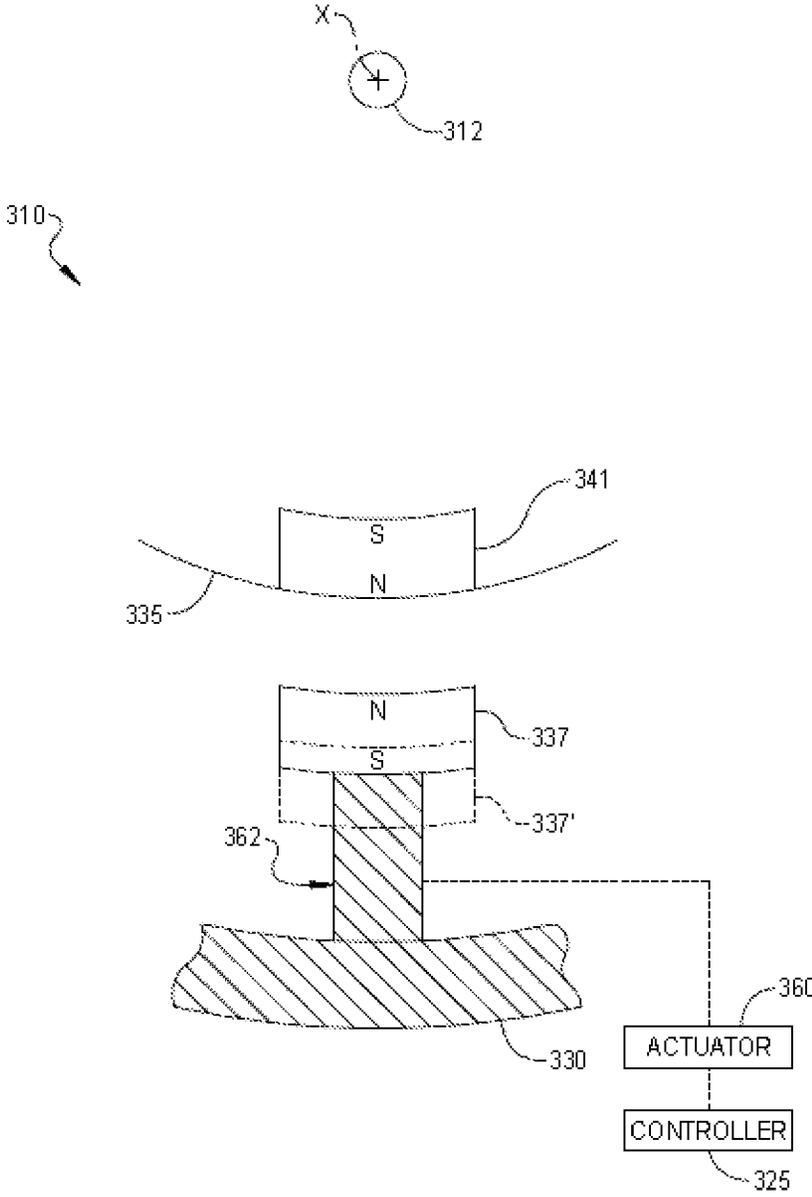


FIG. 9

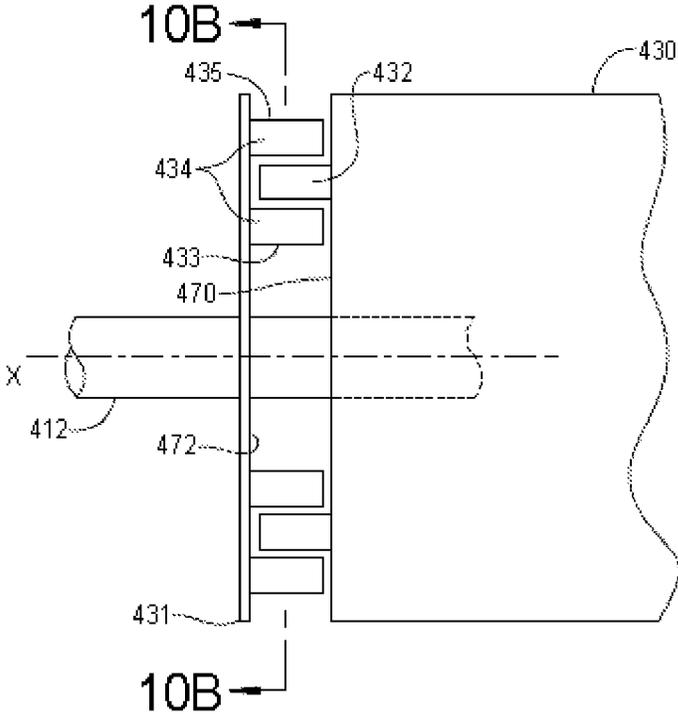


FIG. 10A

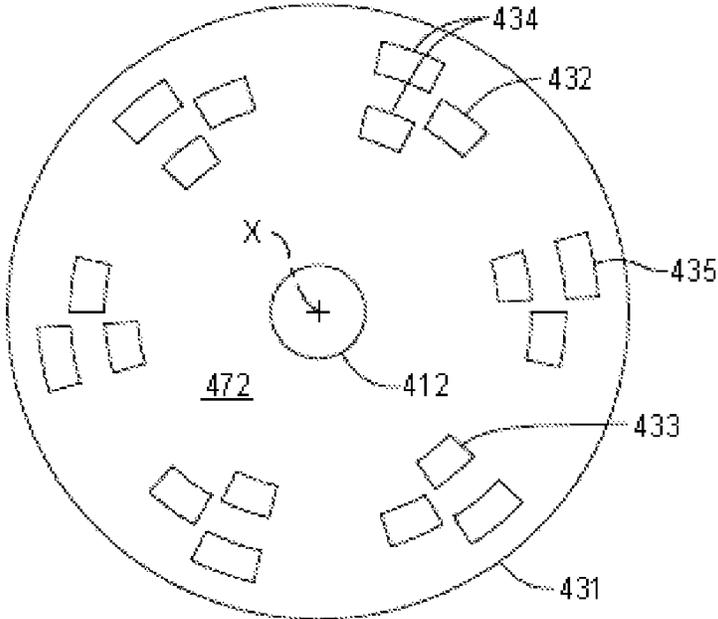


FIG. 10B

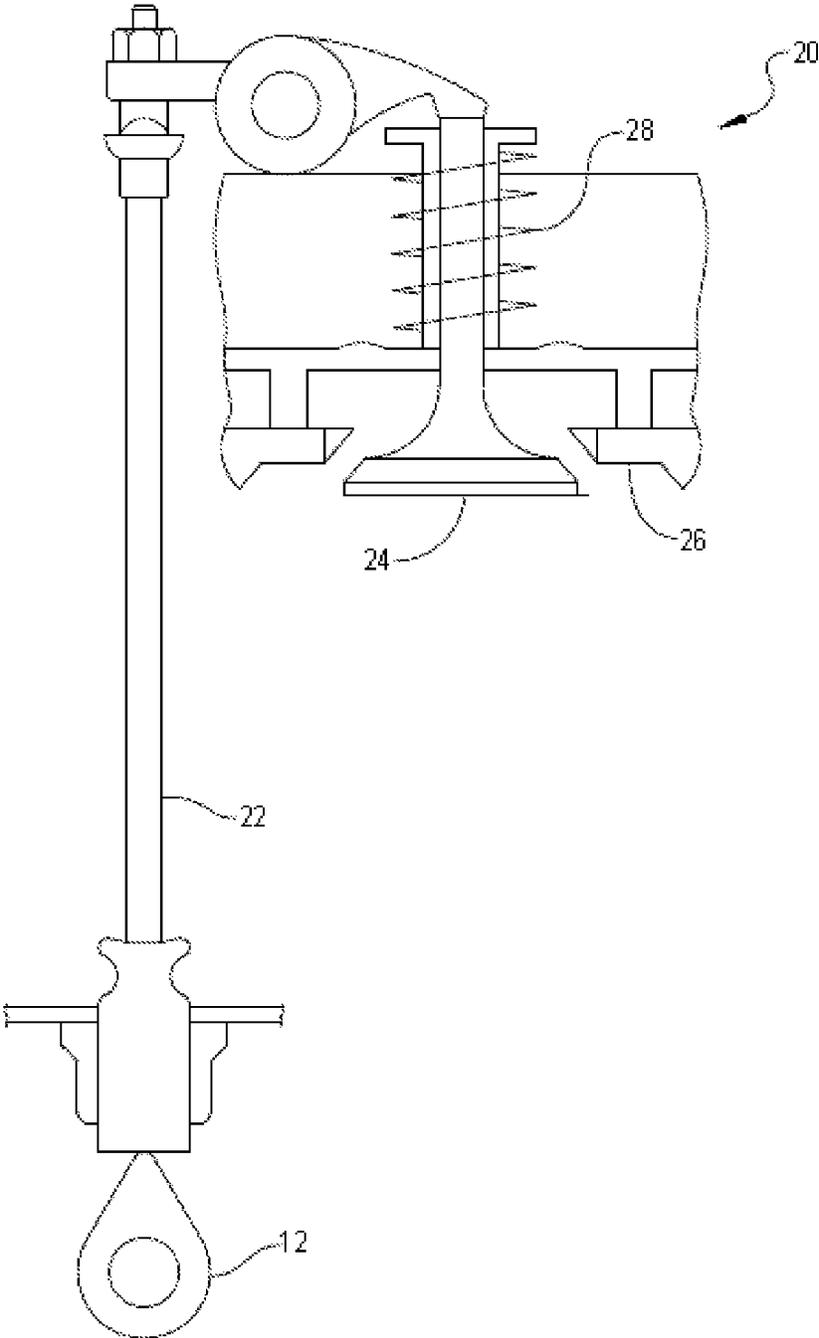


FIG. 11

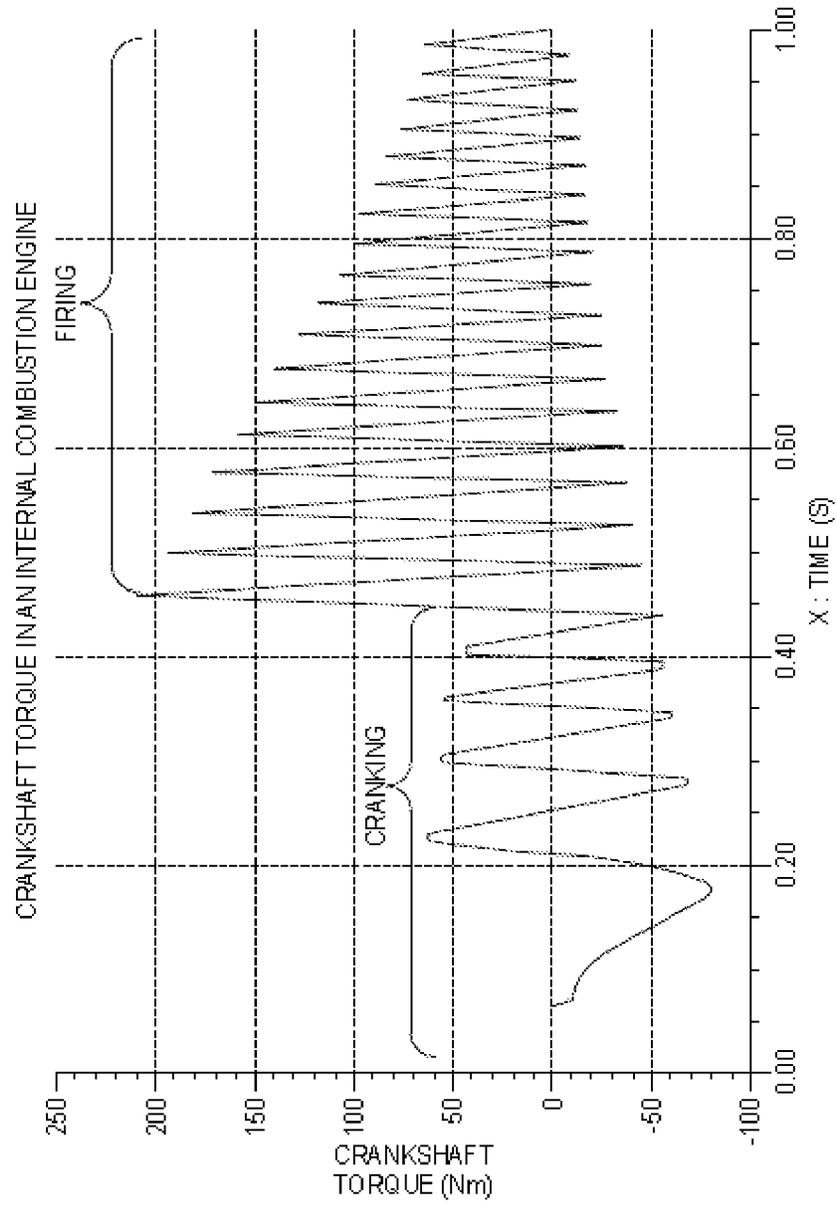


FIG. 12

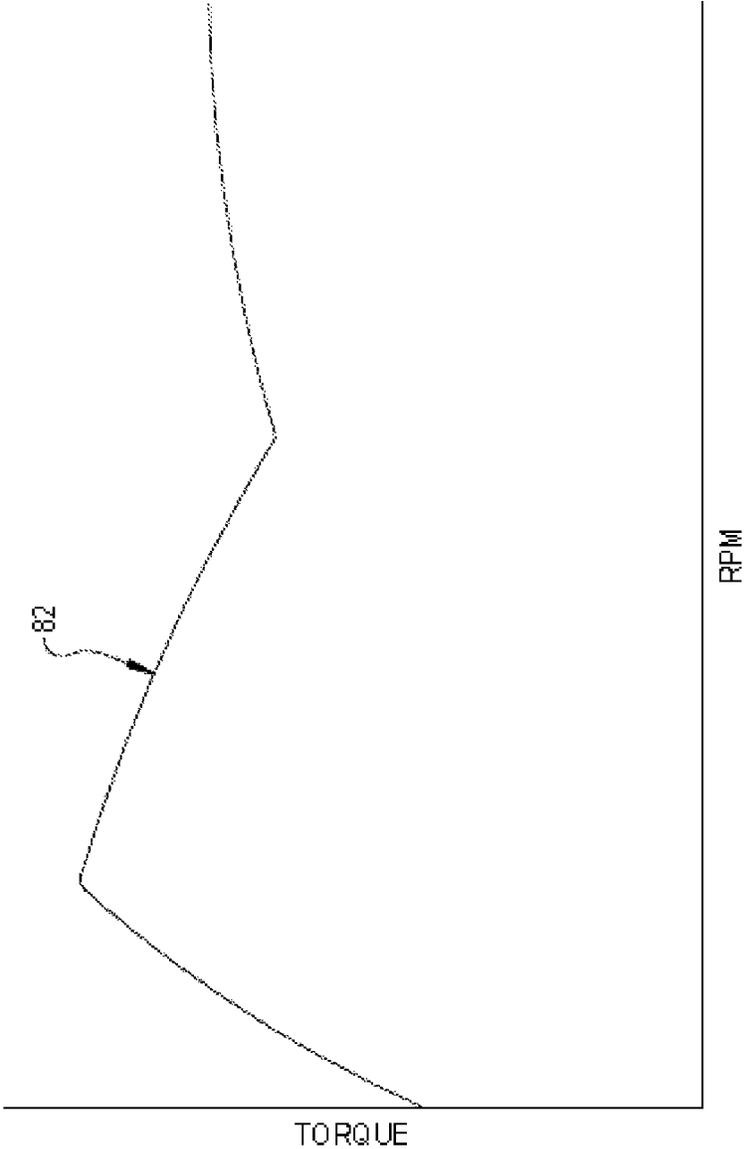


FIG. 13



FIG. 14

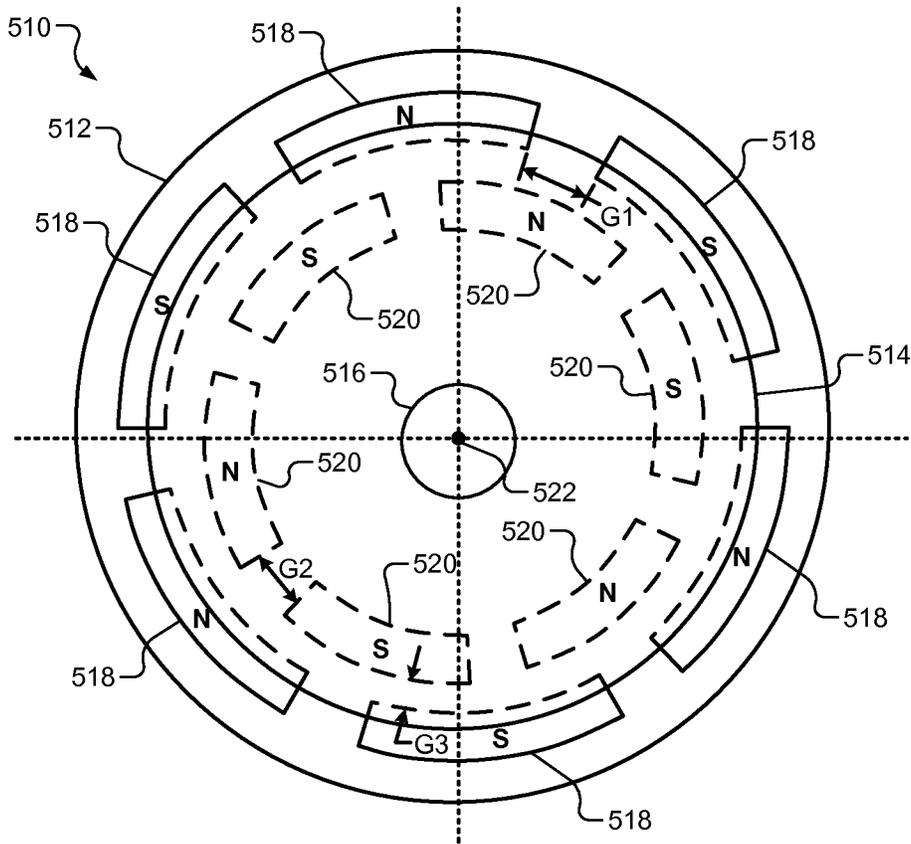


FIG. 15

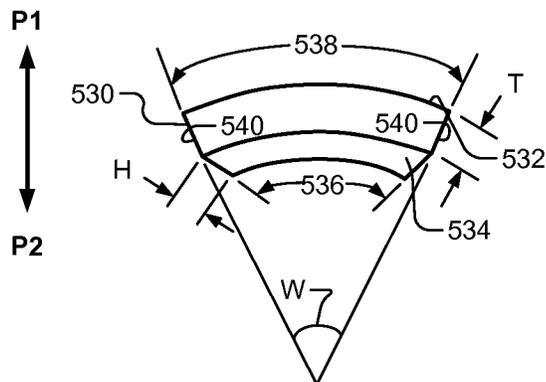


FIG. 16

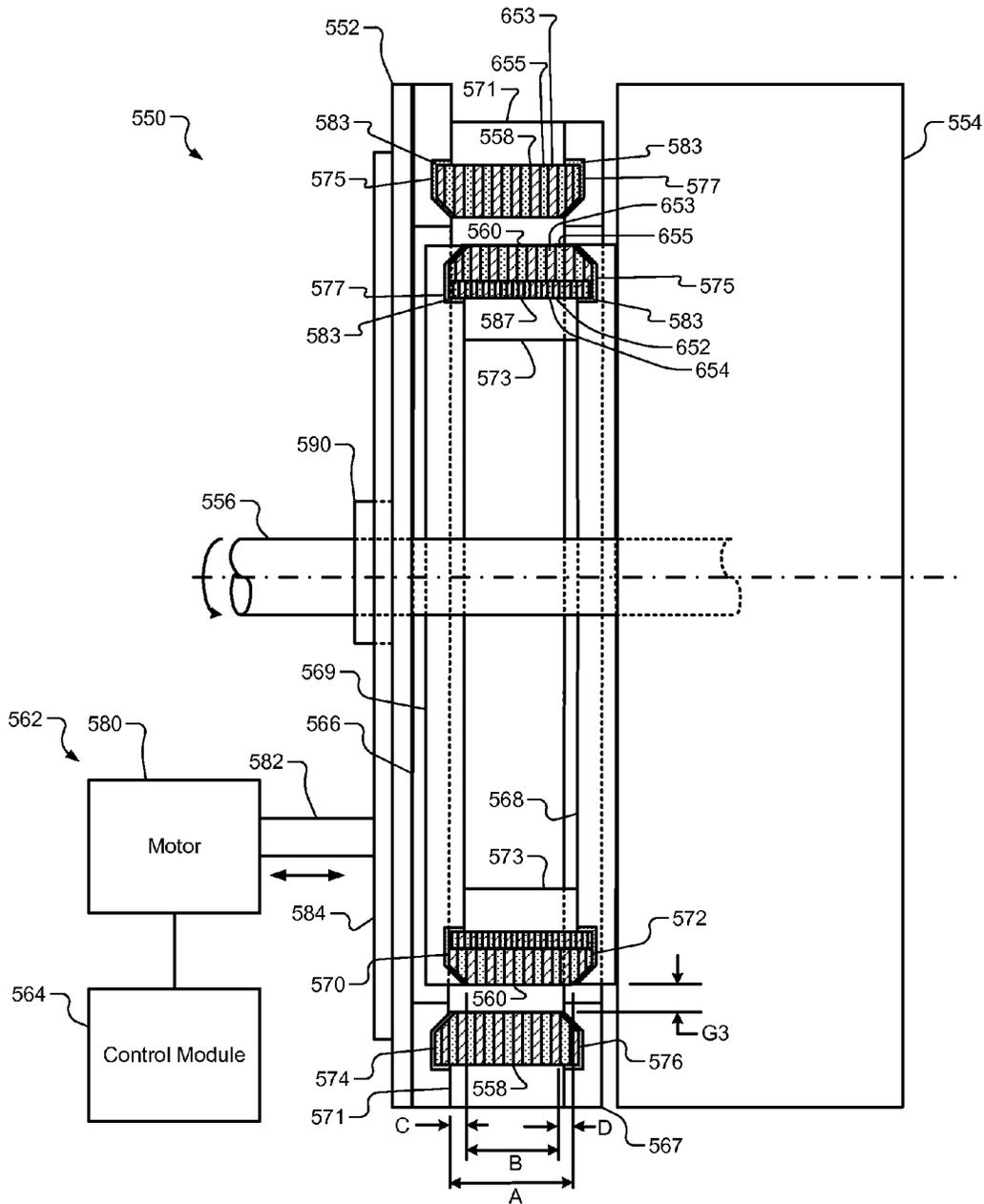


FIG. 17

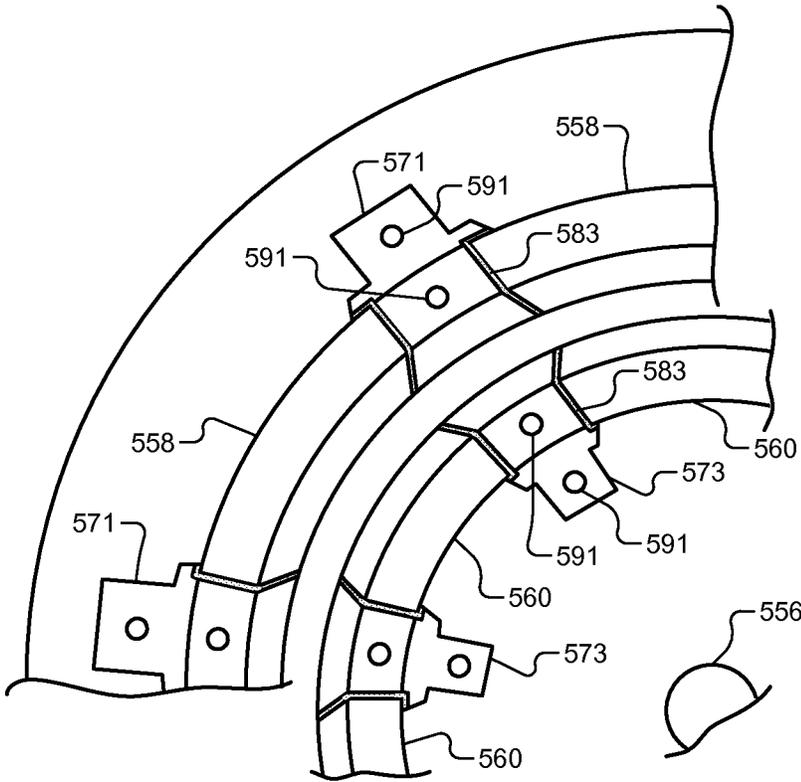


FIG. 18

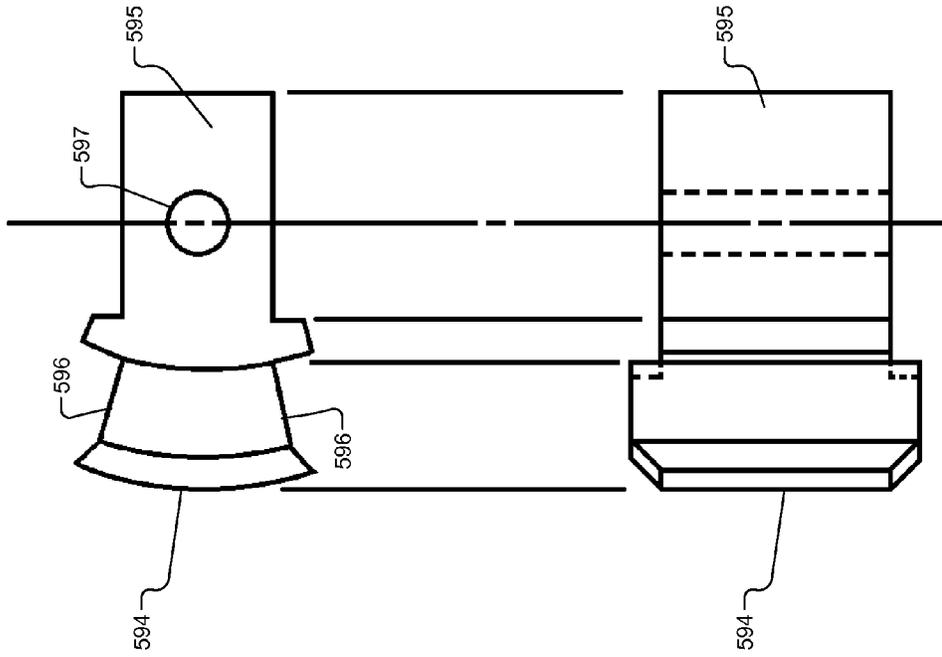


FIG. 19B

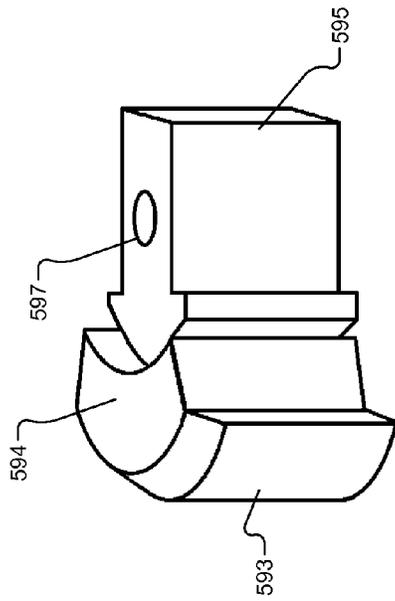


FIG. 19A

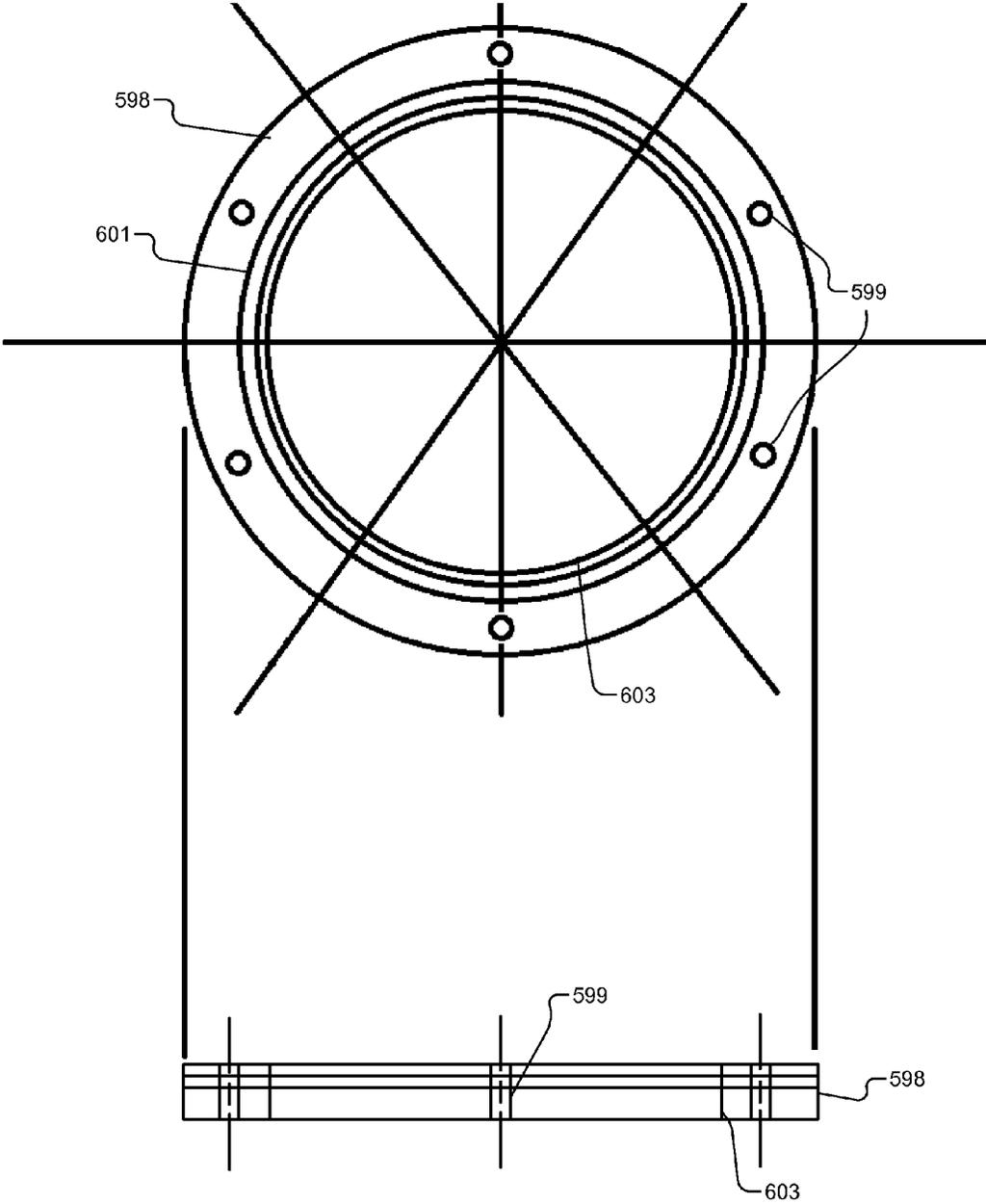


FIG. 20

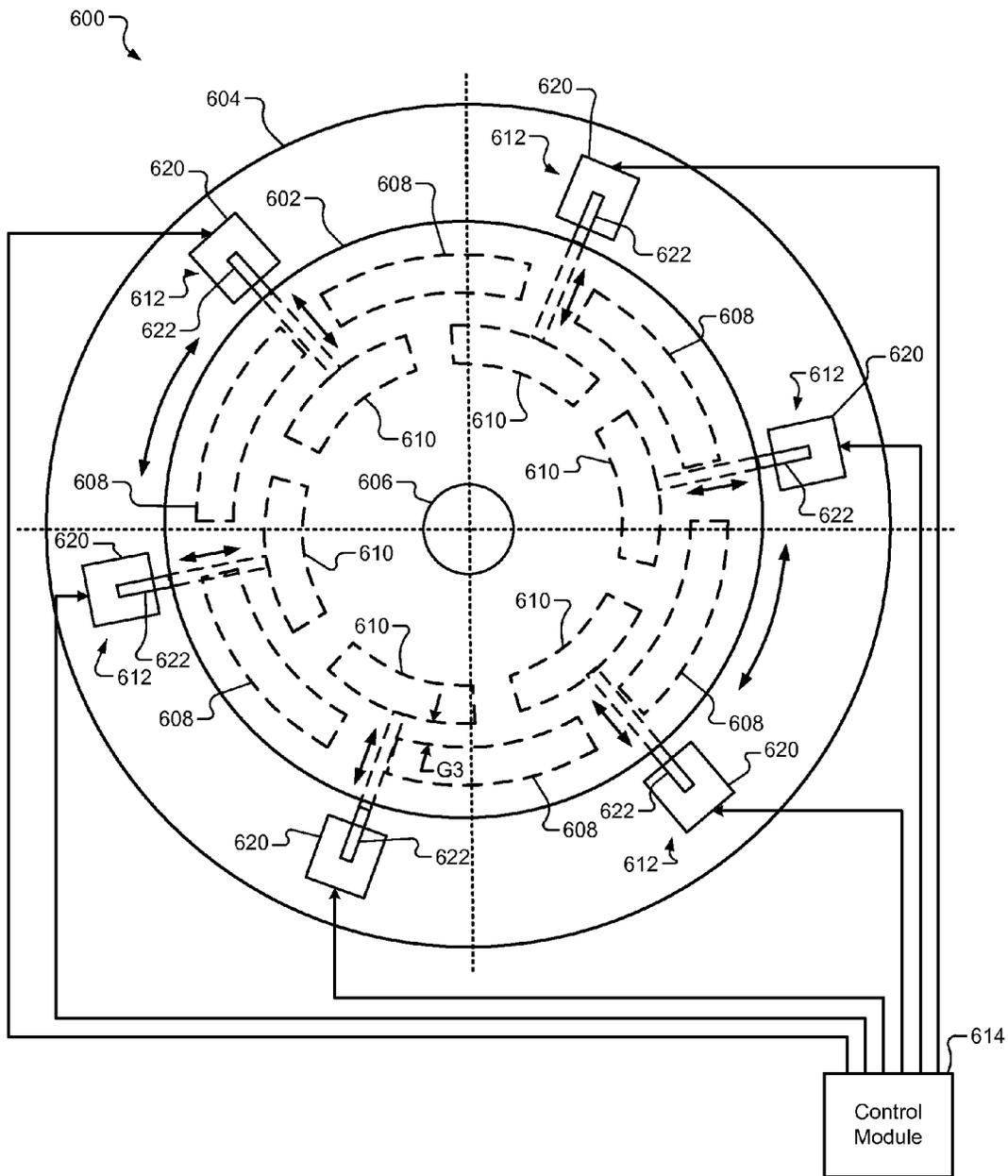


FIG. 21

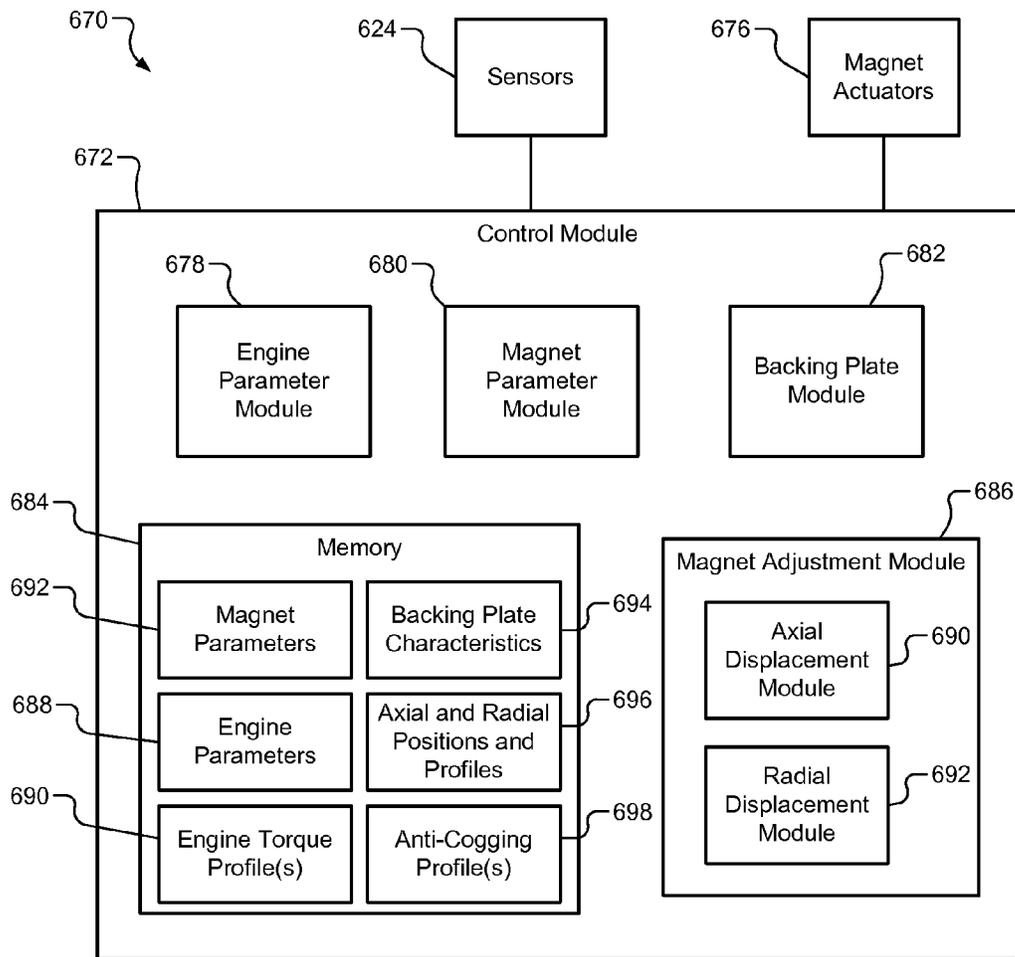


FIG. 22

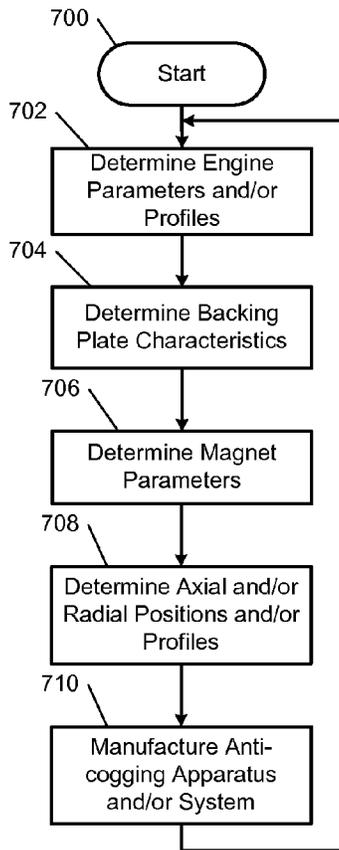


FIG. 23

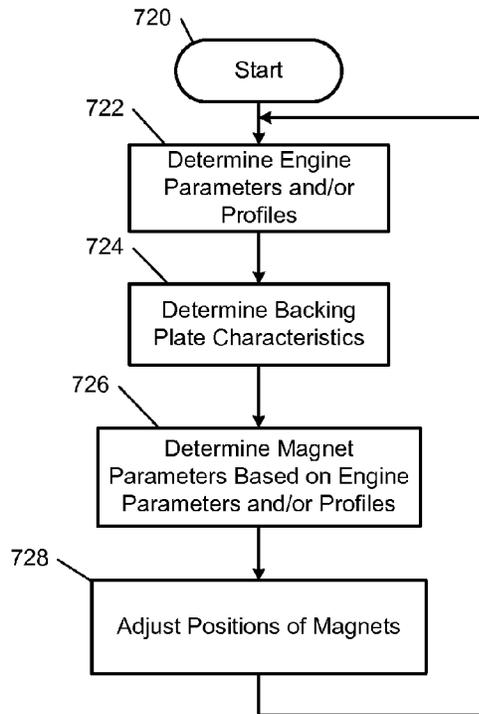


FIG. 24

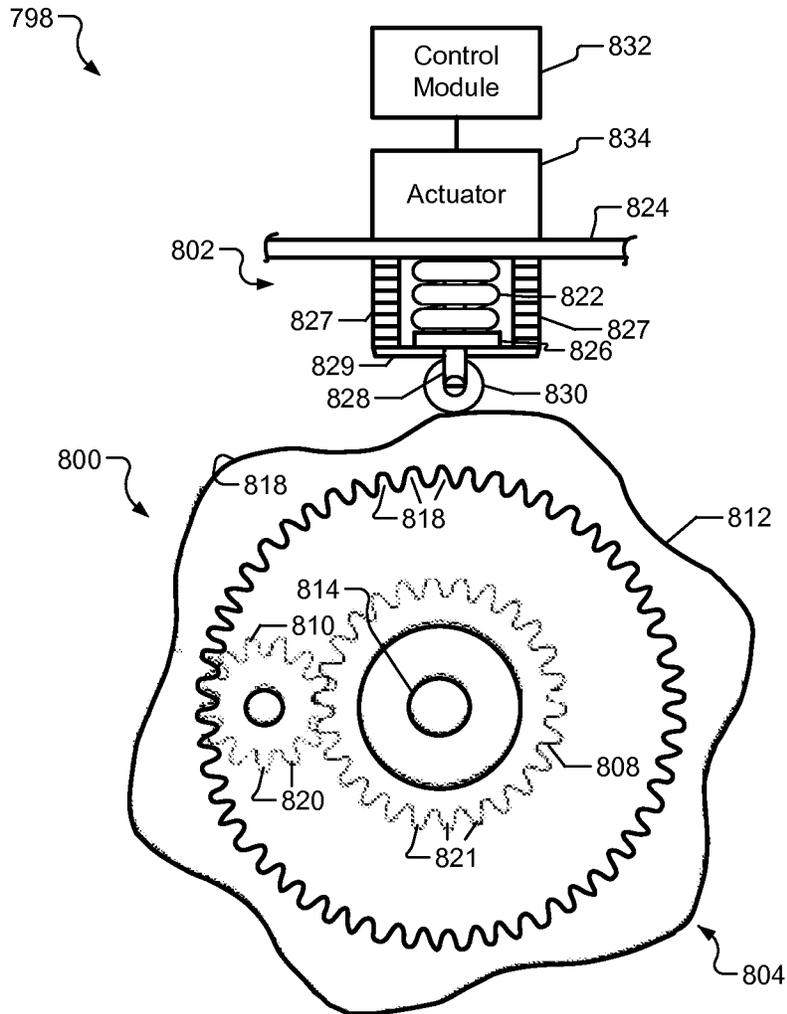


FIG. 25

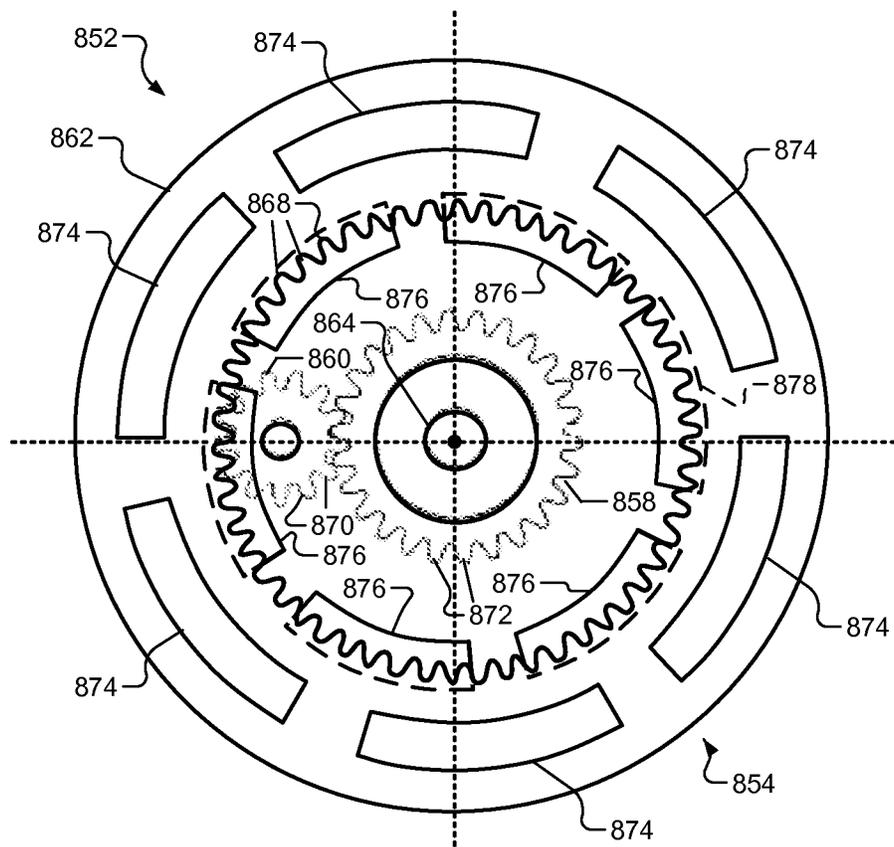


FIG. 26

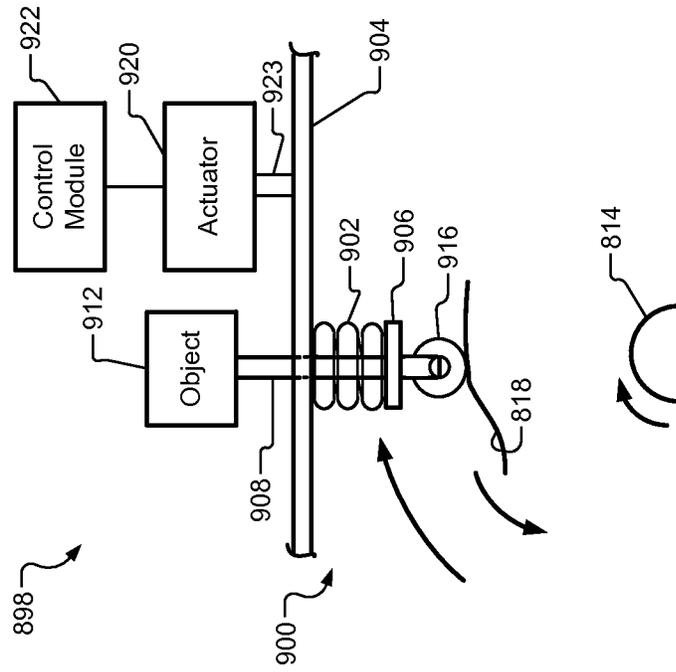


FIG. 27B

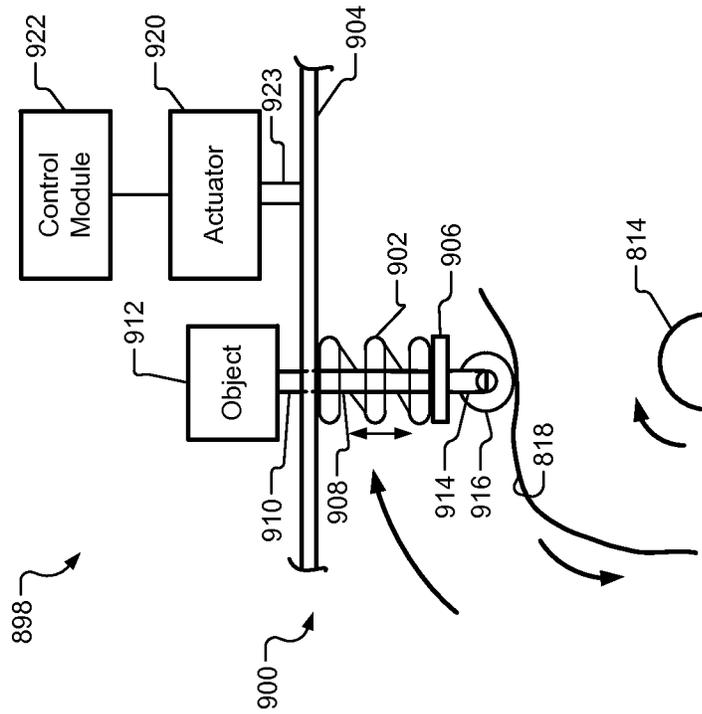


FIG. 27A

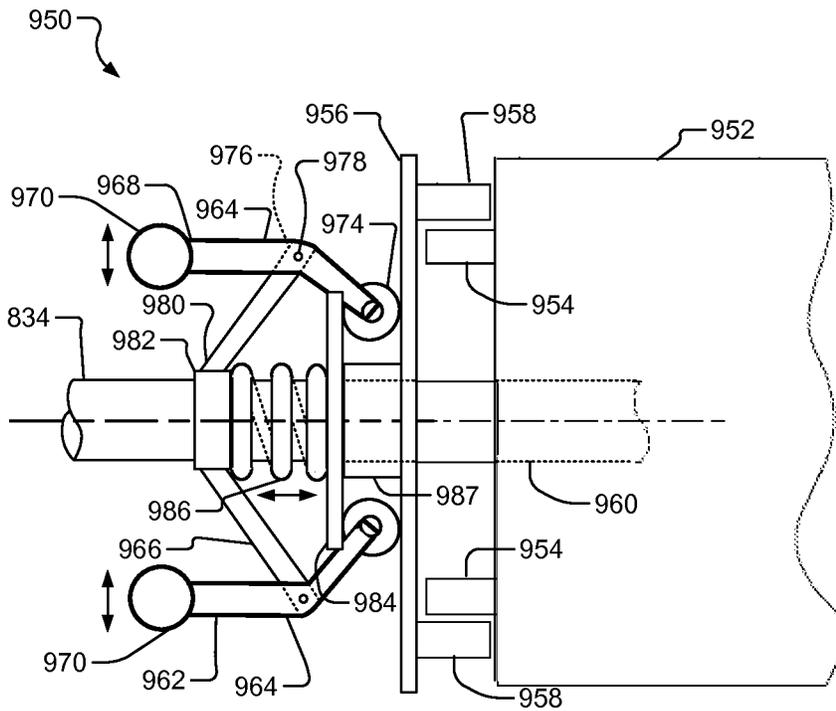


FIG. 28

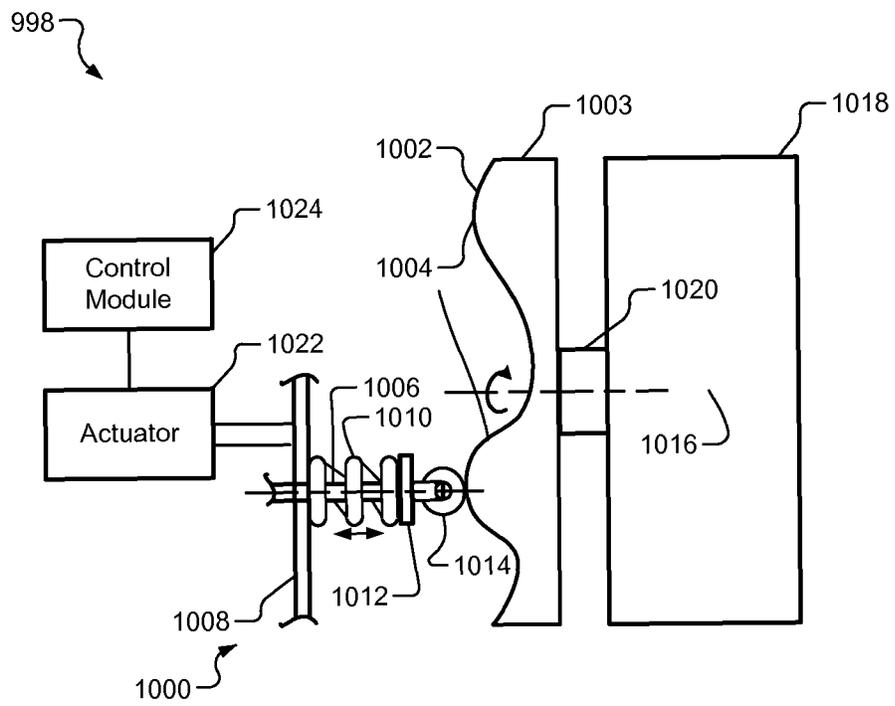


FIG. 29

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**MAGNET-BASED ANTI-COGGING  
APPARATUSES AND SYSTEMS FOR  
APPLYING AN ANTI-COGGING TORQUE  
ON A ROTATING SHAFT**

CROSS-REFERENCE TO RELATED  
APPLICATIONS

The present disclosure is a continuation-in-part application of U.S. patent application Ser. No. 13/234,858 filed on Sep. 16, 2011. This application claims the benefit of U.S. Provisional Application No. 61/403,547, filed on Sep. 18, 2010. The entire disclosure of the above application is incorporated herein by reference.

FIELD

The present disclosure relates to an anti-cogging apparatus and, more particularly, to an anti-cogging apparatuses and systems for counteracting and minimizing cogging of a rotating shaft.

BACKGROUND

This section provides background information related to the present disclosure which is not necessarily prior art.

Many machines (e.g., electric motors) include a rotating shaft to which torque is applied. In an electric motor, for instance, active elements produce interacting magnetic fields that turn a rotor and, thus, a shaft of the motor.

Such machines can also experience cogging. For instance, in an electric motor, passive (non-motive power) interaction between magnetic elements of a stator and a rotor can cause cogging that sequentially and cyclically applies positive torque (aiding rotation of the shaft) and negative torque (hindering rotation of the shaft). The cogging torque can cause undesirable vibrations of the motor and can be especially noticeable at low rotational speeds.

Other machines, such as a cam system, experience cogging loads as well. For instance, some valve systems rotate a shaft to cam a valve open against the biasing force of a spring, wherein further rotation of the shaft allows the spring to bias the valve back closed. Thus, the spring supplies a negative cogging torque to the shaft (i.e., in a direction opposing rotation of the shaft) as the valve opens, and the spring supplies a positive cogging torque to the shaft (i.e., in the same direction as rotation of the shaft) as the valve closes. This cogging torque repeats cyclically as the shaft rotates about its axis.

Similarly, in an internal combustion engine, the crank shaft rotates to actuate a piston in an engine cylinder. As the volume in the cylinder is reduced and pressure increases therein (i.e., during the compression cycle), the crank shaft can experience a resultant negative cogging torque. Conversely, as the volume is increased and pressure decreases therein, the crank shaft can experience a resultant positive cogging torque. Cogging torque can be especially noticeable if combustion is not actually occurring (e.g., during engine startup, where one or more cylinders are deactivated, etc.).

SUMMARY

This section provides a general summary of the disclosure, and is not a comprehensive disclosure of its full scope or all of its features.

An anti-cogging apparatus is provided and includes a first support member, a second support member, a first set of

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magnets, and a second set of magnets. The first support member is configured to be connected to and rotate with a rotatable shaft. The second support member that does not rotate and is configured not to move with the first support member. The first set of magnets is mounted on the first support member in either an alternating polarity or non-alternating polarity configuration. The second set of magnets is mounted on the second support member in either an alternating polarity or non-alternating polarity configuration. The first set of magnets magnetically interacts with the second set of magnets to provide an anti-cogging torque on the rotatable shaft.

In other features, the first support member is configured to be (i) directly connected to and rotate with the rotatable shaft, or (ii) connected through a gearset or speed varying device to the rotatable shaft.

In other features, a number and an arrangement of the first set of magnets, the second set of magnets are such that the anti-cogging torque provided to the rotatable shaft corresponds to cogging inputs to the rotatable shaft.

In other features, the first support member is configured to be connected through a gearset to the rotatable shaft. The first set of magnets, the second sets of magnets and the gearset are configured such that the anti-cogging torque acting on the rotatable shaft corresponds to cogging inputs acting on the rotatable shaft.

In other features, a system is provided and includes a first support member, a second support member, a first set of magnets, a second set of magnets, and an actuator. The first support member is configured to be connected to and rotate with a rotatable shaft. The second support member that does not rotate and is configured not to move with the first support member. The first set of magnets is mounted on the first support member. The second set of magnets is mounted on the second support member. The first set of magnets magnetically interacts with the second set of magnets to provide an anti-cogging torque on the rotatable shaft. The actuator is configured to axially displace one or more magnets in the first set of magnets or in the second set of magnets to adjust the anti-cogging torque applied to the rotatable shaft.

In other features, the first support member is configured to be (i) directly connected to and rotate with the rotatable shaft, or (ii) connected through a gearset or speed varying device to the rotatable shaft.

In other features, a number and an arrangement of the first set of magnets, the second set of magnets are such that the anti-cogging torque provided to the rotatable shaft corresponds to cogging inputs to the rotatable shaft.

In yet other features, an anti-cogging apparatus is provided and includes a first support member, a second support member, a first set of magnets, a second set of magnets, and a backing plate. The first support member is configured to be connected to and rotate with a rotatable shaft. The second support member is configured not to move with the first support member. The first set of magnets is mounted on the first support member. The second set of magnets is mounted on the second support member. The first set of magnets magnetically interacts with the second set of magnets to provide an anti-cogging torque on the rotatable shaft. The backing plate can be attached to the first set of magnets, and/or to the second set of magnets. The backing plate includes one or more magnetically conductive layers and may have one or more insulation layer. The one or more insulation layer may be disposed between corresponding pairs of the magnetically conductive layers.

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In other features, the first support member is configured to be (i) directly connected to and rotate with the rotatable shaft, or (ii) connected through a gearset or speed varying device to the rotatable shaft.

In other features, a number and an arrangement of the first set of magnets and the second set of magnets is such that the anti-cogging torque provided to the rotatable shaft corresponds to cogging inputs to the rotatable shaft.

In other features, an apparatus is provided that improves rotation of a rotatable shaft. The rotatable shaft has a cyclical cogging torque acting thereon in a first direction. The apparatus includes a support member, a first anti-cogging member, a second anti-cogging member, a cam surface, at least one abutment member, and at least one biasing member. The support member is adjacent the rotatable shaft. The rotatable shaft is operable to rotate relative to the support member. The first anti-cogging member is coupled to the support member. The second anti-cogging member is coupled directly or indirectly to the rotatable shaft to rotate based on rotation of the shaft. The cam surface has at least one lobe that is included on one of the first and second anti-cogging members. The at least one abutment member is coupled to the other of the first and second anti-cogging members. The at least one abutment member is operable to abut against the cam surface to provide an anti-cogging torque to the rotatable shaft in a second direction that opposes the first direction to at least partially offset the cogging torque. The at least one biasing member biases the at least one abutment member toward the cam surface.

In other features, an apparatus is provided that improves rotation of a rotatable shaft about an axis. The rotatable shaft has a cyclical cogging torque acting thereon in a first direction. The apparatus includes a device, a differential speed assembly, an abutment member, and a control module. The device rotates relative to the rotatable shaft and has a cam surface. The differential speed assembly connects the device to the rotatable shaft while allowing the rotatable shaft to rotate at a different speed than the rotatable shaft. The abutment member is coupled to the support member and configured to provide an anti-cogging torque to the rotatable shaft in a second direction that opposes the first direction to at least partially offset the cogging torque. The control module controls an amount of the anti-cogging torque provided to the rotatable shaft.

In other features, a method of improving rotation of a rotatable shaft about an axis is provided. The rotatable shaft has a cyclical cogging torque acting thereon in a first direction. The method includes rotating the shaft to cause relative rotation between an abutment member and a camming member. The camming member is configured to interact with the abutment member to provide an anti-cogging torque to the rotatable shaft in a second direction that opposes the first direction to at least partially offset the cogging torque. The method further includes selectively varying an amount of the anti-cogging torque provided to the rotatable shaft.

In still other features, an apparatus that improves rotation of a rotatable shaft is disclosed. The rotatable shaft has a cyclical cogging torque acting thereon in a first direction. The apparatus includes a support member that is adjacent the rotatable shaft, and the rotatable shaft is operable to rotate relative to the support member. The apparatus also includes a first anti-cogging member and a second anti-cogging member that is coupled directly or indirectly to the rotatable shaft for rotation therewith. The apparatus also includes a cam surface that is included on one of the first and second members. Moreover, the apparatus includes an abutment

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member that is coupled to the other of the first and second members. The abutment member is operable to abut against the cam surface to provide an anti-cogging torque to the rotatable shaft in a second direction that opposes the first direction to at least partially offset the cogging torque.

In other features, the second anti-cogging member is coupled to the rotatable shaft via a differential speed assembly. In other features, a number and arrangement of abutment members on the first and second members, in conjunction with a differential speed assembly are such that anti-cogging inputs applied to the rotatable shaft correspond to cogging inputs applied to the rotatable shaft.

Also, an apparatus that improves rotation of a rotatable shaft about an axis is disclosed. The rotatable shaft has a cyclical cogging torque acting thereon in a first direction. The apparatus includes a first support member that is coupled to the rotatable shaft for rotation therewith and a second support member that is adjacent the first support member. The first support member is operable to rotate relative to the second support member. A plurality of first magnetic members is coupled to one of the first and second support members, and the plurality of first magnetic members includes at least one inner magnetic member disposed at a first radial distance from the axis and at least one outer magnetic member disposed at a second radial distance from the axis. The apparatus also includes a second magnetic member coupled to the other of the first and second support members. The second magnetic member is disposed at a third radial distance from the axis, which is greater than the first radial distance and less than the second radial distance. The second magnetic member is operable to magnetically interact with the at least one inner magnetic member and the at least one outer magnetic member to provide an anti-cogging torque to the rotatable shaft in a second direction that opposes the first direction to at least partially offset the cogging torque.

In other features, the first support member is configured to be (i) directly connected to and rotate with the rotatable shaft, or (ii) connected through a gearset or speed varying device to the rotatable shaft.

Moreover, an apparatus that improves rotation of a rotatable shaft about an axis is disclosed. The rotatable shaft has a cyclical cogging torque acting thereon in a first direction. The apparatus includes a first support member that is coupled to the rotatable shaft for rotation therewith and a second support member that is adjacent the first support member. The first support member is operable to rotate relative to the second support member. The apparatus also includes a first magnetic member coupled to one of the first and second support members and a second magnetic member coupled to the other of the first and second support members. The second magnetic member is operable to magnetically interact with the first magnetic member to provide an anti-cogging torque to the rotatable shaft in a second direction that opposes the first direction to at least partially offset the cogging torque. Furthermore, the apparatus includes a controller that controls and varies an amount of the anti-cogging torque provided to the rotatable shaft.

In other features, the first support member is configured to be (i) directly connected to and rotate with the rotatable shaft, or (ii) connected through a gearset or speed varying device to the rotatable shaft.

Still further, a method of improving rotation of a rotatable shaft about an axis is disclosed. The rotatable shaft has a cyclical cogging torque acting thereon in a first direction. The method includes rotating the shaft to cause relative rotation between a first magnetic member and a second

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magnetic member. The second magnetic member is operable to magnetically interact with the first magnetic member to provide an anti-cogging torque to the rotatable shaft in a second direction that opposes the first direction to at least partially offset the cogging torque. The method also includes selectively varying an amount of the anti-cogging torque provided to the rotatable shaft.

In other features, the first support member is configured to be (i) directly connected to and rotate with the rotatable shaft, or (ii) connected through a gearset or speed varying device to the rotatable shaft.

In other features, an apparatus that improves rotation of a rotatable shaft is provided. The rotatable shaft has a cyclical cogging torque acting thereon in a first direction. The apparatus includes a support member that is adjacent to the rotatable shaft. The rotatable shaft operable to rotate relative to the support member. A first anti-cogging member coupled to the support member. A second anti-cogging member is coupled directly or indirectly to the rotatable shaft to rotate based on rotation of the shaft. A cam surface has at least one lobe that is included on one of the first and second anti-cogging members. At least one abutment member is coupled to the other of the first and second anti-cogging members, where the at least one abutment member is operable to abut against the cam surface to provide an anti-cogging torque to the rotatable shaft in a second direction that opposes the first direction to at least partially offset the cogging torque. At least one biasing member biases the at least one abutment member toward the cam surface.

In other features, the second anti-cogging member is coupled to the rotatable shaft via a differential speed assembly. In other features, the differential speed assembly includes two or more gears and is configured such that the second anti-cogging member rotates based on rotation of the rotatable shaft.

In other features, the rotatable shaft is operable to rotate about an axis of rotation and the at least one lobe extends radially with respect to the axis of rotation. In other features, the rotatable shaft is operable to rotate about an axis of rotation and the at least one lobe extends axially with respect to the axis of rotation.

In other features, the at least one abutment member includes abutment members. The cam surface includes lobes. A number and arrangement of the abutment members and a number and arrangement of the lobes are such that the anti-cogging torque acting on the rotatable shaft corresponds to and opposes cogging inputs acting on the rotatable shaft.

In other features, the second anti-cogging member is coupled to the rotatable shaft via a gearset. The at least one abutment member, the at least one lobe, and the gearset are configured such that the anti-cogging torque acting on the rotatable shaft corresponds to and opposes cogging inputs acting on the rotatable shaft.

In other features, the cam surface includes lobes. The at least one abutment member is operable to sequentially abut against the lobes to sequentially provide anti-cogging torque to the rotatable shaft.

In other features, the at least one abutment member includes abutment members. The abutment members are operable to sequentially abut against the at least one lobe to sequentially provide anti-cogging torque to the rotatable shaft.

In other features, the at least one lobe is fixed to the rotatable shaft and the at least one abutment member is operable to move relative to the cam surface. In other features, the apparatus further includes at least one biasing member that biases the at least one abutment member

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toward the cam surface, where the biasing member is a potential energy storage device that includes a helical spring, a leaf spring, or a pneumatic cylinder.

In other features, the at least one abutment member is fixed to the rotatable shaft and is operable to move relative to the cam surface. In other features, the apparatus further includes at least one biasing member that biases the at least one abutment member toward the cam surface, where the biasing member is a potential energy storage device includes a helical spring, a leaf spring, or a pneumatic cylinder.

In other features, the rotatable shaft is a crankshaft of an internal combustion engine. The cogging torque occurs due to varying pressure within an engine cylinder. The anti-cogging torque occurs due to varying biasing loads from the at least one biasing member.

In other features, the apparatus further includes a control module that controls an amount of the anti-cogging torque provided to the rotatable shaft. In other features, the apparatus further includes an actuator. The control module is configured to control the actuator to adjust tension or compression forces on the at least one biasing member. In other features, the at least one biasing member is a variable rate spring. In other features, the at least one abutment member is configured to be aligned along a straight line extending (i) radially from an axis of rotation of the rotatable shaft, or (ii) in an axial direction and parallel to the axis of rotation of the rotatable shaft. The actuator is configured to, along the straight line, (i) actuate the at least one abutment member relative to the support member, or (ii) actuate the support member relative to the at least one abutment member.

In other features, the apparatus further includes an object having a mass and being connected to both the rotatable shaft and the at least one abutment member via a coupling device. The coupling device is configured to adjust the amount of the anti-cogging torque based on centrifugal forces associated with rotation of the object.

In other features, the rotatable shaft is one of: a crankshaft of an internal combustion engine, where the cogging torque occurs due to varying pressure within an engine cylinder; and an input shaft of a camming system, where the cogging torque occurs due to varying biasing loads from the at least one biasing member.

In other features, a method of improving rotation of a rotatable shaft about an axis is provided. The rotatable shaft has a cyclical cogging torque acting thereon in a first direction. The method includes rotating the shaft to cause relative rotation between at least one abutment member and a camming member, where the camming member is configured to interact with the at least one abutment member to provide an anti-cogging torque to the rotatable shaft in a second direction that opposes the first direction to at least partially offset the cogging torque. Selectively varying an amount of the anti-cogging torque provided to the rotatable shaft.

In other features, the varying of the amount of anti-cogging torque includes varying a preload on a biasing member. In other features, the biasing member is a variable rate spring. In other features, the biasing member is an air cylinder and the varying of the amount of anti-cogging torque includes varying a pressure in the cylinder.

Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

## DRAWINGS

The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations, and are not intended to limit the scope of the present disclosure.

FIG. 1 is a side, sectional view of an apparatus that improves rotation of a rotatable shaft according to various exemplary embodiments of the present disclosure;

FIG. 2 is a front, sectional view of the apparatus of FIG. 1;

FIG. 3 is a front, detail view of the apparatus of FIG. 1;

FIG. 4 is a front, sectional view of the apparatus of the present disclosure according to additional embodiments;

FIG. 5 is a front, sectional view of the apparatus of the present disclosure according to additional embodiments;

FIG. 6 is a front, detail view of the apparatus of FIG. 5;

FIG. 7 is a front, detail view of the apparatus of the present disclosure according to additional embodiments;

FIG. 8 is a graph representing operation of the apparatus of the present disclosure showing how the apparatus offsets cyclical cogging torque;

FIG. 9 is a front, detail view of the apparatus of the present disclosure according to additional embodiments;

FIG. 10A is a side view of the apparatus of the present disclosure according to additional embodiments;

FIG. 10B is a section view of the apparatus taken along the line 10B-10B of FIG. 10A;

FIG. 11 is a schematic view of a cam system that can be operably coupled to the anti-cogging apparatus of the present disclosure;

FIG. 12 is a graph representing torque in a crank shaft of an internal combustion engine;

FIG. 13 is a graph representing the maximum cranking torque as a function of engine speed;

FIG. 14 is a graph representing efficiency gains that can be recognized using the anti-cogging apparatus of the present disclosure;

FIG. 15 is an end view of a portion of an anti-cogging apparatus illustrating alternating magnet polarities in accordance with the present disclosure;

FIG. 16 is a perspective view of a magnet in accordance with the present disclosure;

FIG. 17 is a cross-sectional portion of an axial displacement system in accordance with the present disclosure;

FIG. 18 is a quarter end view of a base plate, magnets and wedges of a displacement system in accordance with the present disclosure;

FIGS. 19A-19B are perspective and side views of an inner wedge in accordance with the present disclosure;

FIG. 20 includes side and end views of a retaining ring in accordance with the present disclosure;

FIG. 21 is a radial displacement system in accordance with the present disclosure;

FIG. 22 is a functional block diagram of an anti-cogging control system in accordance with the present disclosure;

FIG. 23 illustrates a method of manufacturing an anti-cogging apparatus and/or system in accordance with the present disclosure;

FIG. 24 illustrates a method of operating an anti-cogging apparatus and/or system in accordance with the present disclosure;

FIG. 25 is a diagram illustrating an anti-cogging system and an end view of a differential speed assembly for an anti-cogging apparatus in accordance with the present disclosure;

FIG. 26 is an end view illustrating a differential speed assembly for another anti-cogging apparatus in accordance with the present disclosure;

FIGS. 27A and 27B are functional block diagrams of an anti-cogging system illustrating states of a centrifugal anti-cogging apparatus in accordance with the present disclosure;

FIG. 28 is a side view of another centrifugal anti-cogging apparatus in accordance with the present disclosure; and

FIG. 29 is a diagram of an anti-cogging system illustrating a side view of an anti-cogging apparatus incorporating a cam surface with lobes extending in an axial direction and in accordance with the presented disclosure.

Corresponding reference numerals indicate corresponding parts throughout the several views of the drawings.

## DETAILED DESCRIPTION

Example embodiments will now be described more fully with reference to the accompanying drawings.

## Mechanical System

Referring initially to FIG. 1, an anti-cogging apparatus 10 is illustrated according to various exemplary embodiments. The apparatus 10 can be operably coupled to a rotatable shaft 12, and the shaft 12 can be part of or otherwise connected to a system 14, such as an electric motor, a crankshaft of an internal combustion engine, a camming system, etc. as will be discussed. A surface having one or more lobes may be referred to herein as a cam surface. A component having a cam surface, such as a camshaft, may be referred to as a cam or camming element.

Operation of the system 14 can impart a cyclical load (i.e., a cogging load or cogging torque) on the shaft 12. For instance, if the system 14 is a known electric motor and the shaft 12 is the output shaft of that motor, cogging torque can occur due to magnetic interaction between the magnets of the rotor and the stator poles. This cogging can occur cyclically at known rotational angles of the shaft 12 relative to the rotational axis X. Thus, the cogging can occur N times during every rotation at predetermined angular positions.

However, the anti-cogging apparatus 10 can facilitate rotation of the rotatable shaft 12 despite this cogging torque as will be discussed in greater detail below. The apparatus 10 generates anti-cogging loads that at least partially offset the cogging loads to thereby facilitate rotation of the shaft 12.

It will be appreciated that the term “cogging” is defined broadly herein to mean any torque load that is imparted on the shaft 12 cyclically at known rotational angles of the shaft 12. Thus, the system 14 could be an electric motor as mentioned above. The system 14 could also be an internal combustion engine, and the shaft 12 could be the crankshaft of the engine, wherein the “cogging” is imparted on the crankshaft as a piston moves within a cylinder to vary pressure therein. The system 14 could also be a known cam system 20 (FIG. 11) and the shaft 12 can be an input shaft that cams a pushrod 22 in one direction to thereby push a valve 24 away from its seat 26 against the biasing force of a biasing member 28. Further rotation of the shaft 12 allows the biasing member 28 to bias the valve 24 back toward the seat 26. Thus, the varying biasing loads from the biasing member 28 can impart a “cogging” on the shaft 12. It will be appreciated, though, that the system 14 could be of any other type without departing from the scope of the present disclosure.

Referring now to FIGS. 1-3, the anti-cogging apparatus 10 will be discussed in greater detail. As shown, the appa-

ratus 10 can include a support member 30 or housing. The support member 30 can be of any suitable shape and construction and can be disposed adjacent the shaft 12. Specifically, the shaft 12 can extend through the support member 30 and can be rotatably supported thereon by one or more bearings 31. Thus, the shaft 12 can rotate relative to the support member 30.

The apparatus 10 can also include a first anti-cogging member 32. The first anti-cogging member 32 can include a rod 34 and an abutment member 36. The rod 34 can be slidably attached to the support member 30 and can slide radially toward and away from the rotational axis X of the shaft 12. Also, in the embodiments illustrated, the abutment member 36 can be a small wheel or roller that is rotatably attached to a forked end 33 of the rod 34; however, the abutment member 36 could be fixed to the rod 34 in some embodiments.

The first anti-cogging member 32 can also include a biasing member 38. The biasing member 38 can be a helical compression spring that is disposed between the forked end 33 of the rod 34 and the support member 30. However, the biasing member 38 could be of another type. The biasing member 38 can bias the abutment member 36 toward the axis of rotation X of the shaft 12.

The apparatus 10 can further include a second anti-cogging member 40. As shown in FIG. 2, the second anti-cogging member 40 can include a cam 42 that is coupled (e.g., fixed) to the shaft 12 for rotation therewith. The cam 42 can include one or more lobes 44 that extend radially away from the axis of rotation X. The lobes 44 can each include a rounded cam surface 46. The cam surface 46 for each lobe 44 can include a leading surface 47 and a trailing surface 49 as shown in FIGS. 2 and 3. Any number of anti-cogging members may be included. Each anti-cogging member and/or cam may include any number of cam lobes. The number of anti-cogging members and the number of cam lobes on each of the anti-cogging members may be selected to provide a resulting number of anti-cogging pulses per revolution of the shaft 12 and/or the cam 42 that is equal to the number of cogging pulses per revolution of the shaft 12 and/or the cam 42.

In the embodiments shown, the cam 42 can include a plurality of lobes 44 that are spaced apart at equal rotational angles about the axis X. In FIG. 2, for instance, the cam 42 includes eight lobes 44 that are spaced apart approximately every forty-five degrees (45°) about the axis X. It will be appreciated, however, that the cam 42 can include any number of lobes 44, and the lobes 44 can be spaced apart at any rotational angle. Moreover, the number of lobes 44 and spacing between the lobes 44 can be configured according to the rotational angles at which cogging occurs on the shaft 12 as will be discussed.

The abutment member 36 can rollingly abut against the cam 42 as the cam 42 rotates with the shaft 12. Specifically, the shaft 12 and cam 42 can be driven in rotation by the system 14 about the axis X in the first direction 43 (FIG. 3). As the abutment member 36 rolls along the leading surface 47 of the lobe 44, the leading surface 47 can push the abutment member 36 and the rod 34 radially away from the axis X against the biasing force of the biasing member 38. As the cam 42 further rotates, the abutment member 36 can roll along the trailing surface 49, and the biasing force of the biasing member 38 can, in turn, impart the anti-cogging torque on the shaft 12 in the first direction 43. The abutment member 36 can sequentially abut against the trailing surface

49 of each lobe 44 such that the anti-cogging torque is applied sequentially to the shaft 12 (i.e., at known rotational angles).

As shown in FIG. 8, the anti-cogging torque (represented by broken line 29) and the cogging torque (represented by solid line 27) can be applied substantially simultaneously. Also, the anti-cogging torque can be approximately equal, but opposite, to the cogging torque to substantially offset the cogging torque.

Specifically, FIG. 8 shows at 27 a single cogging torque pulse, which has a substantially sinusoidal profile as is known in the prior art. At point G, the leading edge of the windings could be aligned with the trailing edge of respective ones of the machine's permanent magnets, thereby imparting approximately no torque on the shaft 12. Then, as the shaft 12 further rotates, positive cogging torque (i.e., torque directed along the same direction as rotation of the shaft 12) increases toward a maximum point H, where the windings are spaced approximately half way across an air gap between adjacent permanent magnets. Subsequently, cogging torque can decrease back to approximately zero (point I), where the windings are spaced at the center of the air gap between adjacent magnets. Then, the cogging torque can decrease to a maximum negative value (point J), where the windings are approximately half way out of the air gap. Next, the cogging torque can increase back toward zero (point K), because the windings have advanced enough to align with the adjacent magnets. It will be appreciated that this cogging torque can repeatedly and cyclically follow the profile graphically represented at 27 in FIG. 8.

However, FIG. 8 also shows the anti-cogging torque that the apparatus 10 provides to offset the cogging torque and provide a resulting torque of zero. Specifically, as the abutment member 36 rolls along the leading surface 47, a negative torque (torque opposing the direction of rotation of the shaft 12) is imparted on the shaft 12, as represented in region A of FIG. 8. Anti-cogging torque increases and then decreases back toward zero (point I) at which point the abutment member 36 is located at the land between the leading surface 47 and the trailing surface 49. Then, as the abutment member 36 rolls along the trailing surface 49, a positive torque is imparted on the shaft 12 as represented in region B of FIG. 8. Anti-cogging torque increases and then decreases back toward zero (point K).

As shown in FIG. 8, the anti-cogging torque pulse (regions A and B) is approximately equal but opposite to the cogging torque pulse 27 for a net of zero (represented by line 23 in FIG. 8). In other words, the angular position (8) at which cogging and anti-cogging occurs and the amounts of the cogging and anti-cogging torques are such that the cogging and anti-cogging torques can substantially offset each other. As such, the apparatus 10 can significantly improve efficiency of the system 14.

FIG. 14 illustrates exemplary improvements in efficiency in the system 14 when the apparatus 10 is used. As shown, the gains are most noticeable at lower RPMs, and the gains decrease as the rotational speed increases.

It will be appreciated that the apparatus 10 can be configured differently than those embodiments illustrated in FIGS. 1-3. For instance, the rod 34, abutment member 36, and biasing member 38 of the first anti-cogging member 32 could be fixed for rotation with the shaft 12 while the cam surface 46 could be fixed on the support member 30.

Also, there can be any number of first and second anti-cogging members 32, 40. For instance, if there are N number of cogging torque pulses per revolution of the shaft 12, there can be a single first anti-cogging member 32 and N number

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of lobes **44** on the second anti-cogging member **40** such that there are  $N$  anti-cogging torque pulses per revolution of the shaft **12**. Alternatively, there can be  $N$  number of first anti-cogging members **32** and a single lobe **44** on the second anti-cogging member **40**. Furthermore, there can be an amount  $A$  of first anti-cogging members **32** and an amount  $B$  of second anti-cogging members **40** such that the product of  $A$  and  $B$  is equal to  $N$  ( $A \times B = N$ ).

Still further, in some embodiments, the first and/or second anti-cogging members **32**, **40** can be operably connected to the shaft **12** in any way other than that shown in FIGS. 1-3. For instance, where the system **14** is an electric motor, the second anti-cogging member **40** could be connected via a gearset (not shown) to the rotor of the electric motor, whereby the combination of gear ratio, the number of lobes **44**, and the number of first anti-cogging members **32** produces the  $N$  number of anti-cogging torque pulses per revolution of the shaft **12**.

Additionally, it will be appreciated that the amount of anti-cogging torque can be affected by the profile (e.g., slope) of the cam surface **46**, the spring constant of the biasing member **38**, etc. Thus, these features can be configured to produce the desired anti-cogging torque.

Moreover, the biasing member **38** could be of any type other than the helical spring illustrated in FIGS. 1-3. For instance, as shown in FIG. 4, the biasing member **38'** of the first anti-cogging member **32'** can include a leaf spring, a pneumatic cylinder and/or other potential energy storage device. Thus, the biasing member **38'** can resiliently flex as the cam **42'** rotates with the shaft **12'** to supply the anti-cogging torque as discussed above.

#### Magnetic/Electrical System

Referring now to FIGS. 5 and 6, additional embodiments of the anti-cogging apparatus **110** will be discussed in detail. Components that correspond to those in the embodiments of FIGS. 1-3 are indicated with corresponding reference numerals increased by 100.

As shown, the anti-cogging apparatus **110** includes a first support member **130** and a second support member **135**. The apparatus **110** includes at least one first anti-cogging member **132** and one or more second anti-cogging member **140**. In the embodiments shown, the first anti-cogging member **132** can include a first magnetic member **137** (e.g., a permanent magnet), and the second anti-cogging members **140** can each include a second magnetic member **141**. It will be appreciated that there can be any number of first and second magnetic members **137**, **141**.

The first magnetic member **137** can be fixed to the first support member **130** and can extend radially inward toward the rotational axis  $X$ . The second support member **135** can include a plurality of lobes **144** that extend radially away from the axis  $X$ , and the second magnetic members **140** can be fixed to the respective radial ends of the lobes **144**. Thus, as the shaft **112** rotates about the axis  $X$ , the first magnetic member **137** can sequentially align in an imaginary straight radial line with the second magnetic members **141**.

Also, the second magnetic members **141** can each be arranged with one magnetic pole (e.g., the north pole) facing radially outward. The first magnetic member **137** can be arranged with the same magnetic pole (e.g., the north pole) facing radially inward. Thus, as shown in FIG. 6, as one of the second magnetic members **141** moves immediately adjacent the first magnetic member **137**, the magnetic members **137**, **141** can magnetically repel each other.

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FIG. 6 illustrates interaction between a single pair of first and second magnetic members **137**, **141**. When rotating from position  $A$  to position  $B$ , the magnetic members **137**, **141** magnetically repel each other, resulting in a negative torque being applied to the shaft **112**, which increases as the magnetic members **137**, **141** approach each other and then begins to reduce as the moment arm acting on the shaft **112** decreases. (This is represented by region  $A$  in FIG. 8.) When the magnetic members **137**, **141** are in position  $B$  shown in FIG. 6, the repulsive force therebetween is at a maximum. However, since the members **137**, **141** are aligned radially, the moment arm (and the torque) is substantially zero. Then, as the magnetic members **137**, **141** move to position  $C$  of FIG. 6, the repulsive force therebetween causes a positive torque on the shaft **112** as represented in region  $B$  of FIG. 8.

It will be appreciated that the amount of anti-cogging torque can be dependent upon the field strength of the magnetic members **137**, **141**, the radial distance between the magnetic members **137**, **141**, the size and shape of the magnetic members **137**, **141**, the radial distance of the magnetic members **137**, **141** from the axis  $X$ , etc. Thus, each of these variables can be configured to produce the desired anti-cogging torque.

As discussed above, the number and relative position of the first and second magnetic members **137**, **141** can be configured such that the anti-cogging torque is applied approximately concurrently with the cogging torque such that the two torques at least partially offset. Thus, the overall system efficiency can be improved, vibration of the shaft **112** can be reduced, etc.

Those having ordinary skill in the art will appreciate that the arrangement of the magnetic members **137**, **141** could be varied such that the magnetic members **137**, **141** magnetically attract each other. Whether the magnetic members **137**, **141** attract or repel each other could depend on whichever arrangement most effectively offsets cogging.

Referring now to FIG. 7, the anti-cogging apparatus **210** will be discussed according to additional embodiments. Components that correspond to those in the embodiments of FIGS. 1-3 are indicated by corresponding reference numerals increased by 200.

As shown, the anti-cogging apparatus **210** can include first and second magnetic members **237**, **241**. However, the first magnetic member **237** can include a ferromagnetic material with windings **239** thereon. Thus, the first magnetic member **237** can operate as an electromagnet (i.e., with a magnetic flux that varies according to the current within the windings **239**).

In the embodiments illustrated, the second magnetic member **241** includes permanent magnets. However, it will be appreciated that the second magnetic member **241** could include windings **239** to operate as an electromagnet while the first magnetic member **237** includes a permanent magnet. In still other embodiments, both the first and second magnetic members **237**, **241** can include windings **239** to operate as electromagnets.

The windings **239** can be operably connected to a controller (or control module) **225**, which is schematically illustrated in FIG. 7. The controller **225** can include a variable current source, programmed logic, etc., and the controller **225** can variably control the current flowing through the windings **239** to thereby vary the magnetic flux of the first magnetic member **237** during operation. As such, the controller **225** can vary the magnetic flux to thereby vary the anti-cogging torque imparted to the shaft **212**.

The embodiments of FIG. 7 could be used where the apparatus **210** is operably coupled to an electric motor. In

some cases, the magnetic flux in the pole cores of the motor might be varied to control the rotational speed of the shaft 212, which would change the cogging torque applied to the shaft 212. As a result, the controller 225 could control the amount of current flowing through the windings 239 to thereby vary the magnetic flux of the first magnetic member 237 to offset the varying cogging torque. Thus, the anti-cogging torque can be varied according to the amount of cogging torque applied to the shaft 212, according to the relative angular position of the first and second magnetic members 237, 241, etc.

In some embodiments, the controller 225 could be in communication with a known torque sensor (not shown) that automatically detects the amount of cogging torque applied to the shaft 212. As a result, the controller 225 could automatically adjust the magnetic flux of the first magnetic member 237 to supply an equal, but opposite, anti-cogging torque to the shaft 212.

Referring now to FIG. 9, additional embodiments of the anti-cogging apparatus 310 will be discussed. Components that correspond to components of the embodiments of FIGS. 1-3 are indicated with corresponding reference numbers increased by 300.

As shown, the first magnetic member 337 can be a permanent magnet that is fixed to a rod 362. The rod 362 can be moveably (e.g., slidably) coupled to the first support member 330 so as to be moveable toward and away from the axis X. In the embodiments illustrated, the rod 362 and first magnetic member 137 can move along a straight radial line relative to the axis X. A first radial position is indicated at 337 and a second radial position is indicated at 33T.

The rod 362 can also be operably coupled to an actuator 360, which actuates the rod 362 and magnetic member 137 radially. The actuator 360 can be of any suitable type, such as an electric actuator. In some embodiments, the rod 362 can be threaded to the support member 330, and the actuator 360 can threadably advance the rod 362 radially such that the rod 362 remains in place relative to the support member 330 even when the actuator 360 is switched OFF. The actuator 360 can be in communication with a controller (or control module) 325 for controlling radial movement of the first magnetic member 137.

Accordingly, the distance (i.e., the air gap) between the first magnetic member 337 and the second magnetic member 341 can be controlled by radially moving the first magnetic member 337. As the air gap is reduced, the anti-cogging torque is increased and vice versa. Thus, the anti-cogging torque imparted to the shaft 312 can be varied, for instance, according to the amount of cogging torque being applied to the shaft 312.

It will be appreciated that the second magnetic member 341 could be moveable radially relative to the axis X instead of or in addition to the first magnetic member 337. It will also be appreciated that both magnetic members 337, 341 could be moveable by the actuator 360.

Referring now to FIGS. 10A and 10B, additional embodiments of the anti-cogging apparatus 410 will be discussed. Components that correspond to those of the embodiments of FIGS. 1-3 are indicated with corresponding reference numbers increased by 400.

As shown, the apparatus 410 can include a first support member 430 that is tubular and that includes an end face 470. The apparatus 410 can also include a second support member 431 that is flat and disc-shaped so as to include a surface 472 that faces the end face 470 of the first support member 430. The second support member 431 can be coupled (e.g., fixed), directly connected, and/or connected

through a gearset or similar speed varying device to the shaft 412 for rotation therewith relative to the first support member 430.

The apparatus 410 can also include a plurality of first magnetic members 432 that are fixed to the end face 470 of the first support member 430. There can be any number of first magnetic members 432, and the first magnetic members 432 can be each disposed at the same radial distance (i.e., a third radial distance) away from the axis X and can be equally spaced away from each other at equal angular distances. For instance, there can be six first magnetic members 432 at every sixty degrees (60°) about the axis X.

Furthermore, the apparatus 410 can include a plurality of second magnetic members 434. The second magnetic members 434 can be arranged in pairs that are aligned along a straight, radial line. Each pair can include an inner magnetic member 433 and an outer magnetic member 435. The inner magnetic members 433 can be annularly arranged about the axis X at a radial distance (i.e., a first radial distance). The outer magnetic members 435 can be annularly arranged about the axis X at a radial distance that is greater than that of the inner magnetic members 433 (i.e., a second radial distance). The radial distance of first magnetic members 432 can be greater than that of the inner magnetic members 433 and less than that of the outer magnetic members 435. Stated differently, the inner magnetic members 433, the first magnetic members 432, and the outer magnetic members 435 can be arranged in concentric circles about the axis with the ring of first magnetic members 432 disposed between the inner and outer magnetic members 433, 435.

As the shaft 412 rotates, the inner and outer magnetic members 433, 435 can rotate relative to the first magnetic members 432. As the first magnetic members 432 move between respective pairs of the inner and outer magnetic members 433, 435, the first magnetic members 432 can magnetically interact (e.g., repel) the inner and outer magnetic members 433, 435 to cause the anti-cogging torque to be imparted to the shaft 412. It will be appreciated that because the first magnetic members 432 move between the inner and outer magnetic members 433, 435, the force of magnetic repulsion can be increased. As a result, anti-cogging torque can be increased (e.g., approximately doubled).

The embodiments of FIGS. 10A and 10B could be varied. For instance, there could be multiple concentric rings of first magnetic members 432, and each ring could be radially arranged to move between respective pairs of rings of inner and outer magnetic members 433, 435. Accordingly, anti-cogging torque can be further increased.

As mentioned above, the anti-cogging apparatus 10, 110, 210, 310, 410 can be operably coupled to an output shaft of an electric motor to offset the cogging that occurs during operation. The apparatus 10, 110, 210, 310, 410 could also be operably coupled to an input shaft of a cam system (FIG. 11) to offset cogging in largely the same fashion. Moreover, the apparatus 10, 110, 210, 310, 410 could be operably coupled to a crankshaft of an internal combustion engine. This can be advantageous, for instance, when combustion is not occurring (e.g., at engine startup, in an engine with certain cylinders that are deactivated, etc.).

FIG. 12 graphically represents the torque on a crankshaft of a known internal combustion engine over time. Also, FIG. 13 includes line 82 that represents the variation of the maximum cranking torque as a function of the engine speed (RPM). As shown in FIG. 12, the torque is cyclical and changes from an initial cranking torque sequence (before combustion occurs in the cylinders) to a firing torque

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sequence (during combustion) as indicated in FIG. 12. In each of these sequences, there are periods in which the torque is negative. The apparatus 10, 110, 210, 310, 410 could be operably connected to the crankshaft to substantially reduce (e.g., eliminate) these periods of negative torque affecting the crankshaft. As such, the crankshaft would experience less torque resisting rotation, the engine could be operated more efficiently, a smaller starter motor could be used, idle speed can be reduced to reduce fuel usage, etc.

In summary, the anti-cogging apparatus 10, 110, 210, 310, 410 of the present disclosure can offset cogging torques that are imparted on a rotating shaft 12, 112, 212, 312, 412. As such, the apparatus 10, 110, 210, 310, 410 can improve efficiency, can reduce vibration, and otherwise improve rotation of the shaft 12, 112, 212, 312, 412. Also, the apparatus 10, 110, 210, 310, 410 could be incorporated into an existing electric motor, cam system, IC engine, or other existing design to thereby improve efficiency, etc. The apparatus 10, 110, 210, 310, 410 can also be very compact, even when incorporated into existing machines.

FIG. 15 shows an end view of a portion 510 of an anti-cogging apparatus. The portion 510 includes a first support member (or ring) 512 and a second support member (or ring) 514. The first support member 512 may be attached to, in a fixed relationship with, and/or rotate with a shaft 516. The first support member 512 may be axially displaced along the shaft 516. The shaft 516 may be, for example, a crankshaft or camshaft of an engine or other rotatable shaft. The shaft may be on a device other than an engine, for example, on a camshaft of a hydraulic pump.

The first support member 512 may be, for example, a flywheel, a ring connected to the flywheel, or other component connected to the shaft 516. The second support member 514 may be in a fixed (or stationary) position and not rotate with the first support member 512 and/or the shaft 516. The second support member 514 may be connected to and/or integrally formed as part of, for example: an engine block; a transmission bell housing; a component of an engine; a transmission, and/or a torque converter; etc.

A first set of magnets 518 is mounted on the first support member 512. The first set of magnets 518 may be secured to the first support member 512 to withstand speeds of the shaft 516 and expected loads on the first set of magnets 518. The first set of magnets 518 and the second set of magnets 520 may be wedge-shaped as shown or may have a different shape. A second set of magnets 520 are mounted on the second support member 514. The first set of magnets 518 may be rotated (i) about a center axis 522 and in a fixed relationship with the shaft 516, and (ii) within or around the second set of magnets 520, as shown. The first support member 512 and the first set of magnets 518 may be collectively referred to as rotor. The second support member 514 and the second set of magnets 520 may be collectively referred to as a stator. The sets of magnets 518, 520 may deliver a sinusoidal reversing torque to the shaft 516 and provide peak torque magnitudes matching peak reversal torque magnitudes produced during, for example, compression strokes of an engine.

The first set of magnets 518 may have a north pole and a south pole (designated N and S) and may be mounted on the first support member 512 in an alternating polarity configuration as shown. Although shown in an alternating polarity configuration, the first set of magnets may be configured in a non-alternating polarity configuration. As shown, every other magnet in the first set of magnets 518 has a north pole facing the second support member 514 and the other mag-

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nets in the first set of magnets 518 has a south pole facing the second support member 514. The north poles and south poles of each of the first set of magnets 518 may either face the first support member 512 or the second support member 514.

The second set of magnets 520 may have a north pole and a south pole (also designated N and S) and may be mounted on the second support member 514 in an alternating polarity configuration, as shown. Although shown in an alternating polarity configuration, the second set of magnets may be configured in a non-alternating polarity configuration. The north poles and south poles of each of the second set of magnets 520 may either face the first support member 512 or the second support member 514. The alternating polarity configurations of the sets of magnets 518 and 520 provide an alternating torque. Increased torque is provided due to the alternating polarity configurations and spacing: between adjacent pairs of the first set of magnets (identified as gap G1); between adjacent pairs of the second set of magnets (identified as gap G2); and between the first and second magnets (identified as gap G3). The gaps G1-G3 may be adjusted to provide a determined torque (e.g., anti-cogging torque). The gap G3 (referred to as the radial gap) may be adjusted during operation of the anti-cogging apparatus, as shown in FIG. 18. The gap G3 may be maintained within a predetermined range and/or at a value greater than a predetermined value to maintain a minimum torque and to prevent contact between the sets of magnets 518, 520.

The sets of magnets 518, 520 have various associated magnet parameters. Each of these parameters may be adjusted during manufacturing of the sets of magnets 518, 520 and/or may be adjusted during operation and/or use of the sets of magnets 518, 520. Some of the magnet parameters are illustrated in FIG. 16. Referring now also to FIG. 16, which shows a perspective view of a magnet 530. The magnet 530 may refer to any one of the magnets in the sets of magnets 518, 520.

The magnet 530 has a semi-circular prism shape with an outer circumferential side 532 and an inner circumferential side 534. An inner circumferential length 536 of the inner circumferential side 534 is less than an outer circumferential length 538 of the outer circumferential side 532. The magnet 530 is polarized and includes a first pole P1 (e.g., north or south pole) and a second pole P2 (e.g., north or south pole). The first pole is on the outer circumferential side 532. The second pole is on the inner circumferential side 534.

The magnet 530 has static parameters including a height H, a width W, a thickness (or depth) T, the inner circumferential length 536, and the outer circumferential length 538. The width W may refer to an angle between lines tangent radial sides 540 of the magnet 530. The lines intersect and form the angle labeled W. As a few examples, the width W may be 5°, 10°, 30° or 45°. For example, in a six-cylinder engine implementation, the width W of the first set of magnets 518 of FIG. 15 may be 45° with gaps (e.g., the first gap G1) between adjacent pairs of the first set of magnets 518 having corresponding angles of 15°. Thus, the sum of the widths of the first sets of magnets 518 and the gaps between the adjacent pairs of the first set of magnets 518 is 360°.

Although in one implementation the static parameters associated with the magnets in the first set of magnets 518 are the same, the static parameters may be different from magnet to magnet. As an example, the thicknesses of all of the magnets in the first set of magnets 518 may be the same or different. This holds true for the magnets in the second set of magnets 520. Thus, the static parameters of the second set

of magnets **520** may be the same or different from magnet to magnet. Although certain static parameters (e.g., the width, the thickness, the inner circumferential length, and the outer circumferential length) of the first set of magnets **518** are different than the static parameters of the second set of magnets **520**, other static parameters of the first set of magnets **518** may be the same or different than that of the second set of magnets **520**. For example, the heights and/or thicknesses of the first set of magnets **518** may be the same or different than the heights and/or thicknesses of the second set of magnets **520**.

The static parameters may also include the types, compositions, and/or quantities of materials used to form each magnet. As an example, the magnet **530** may be formed of a N35 grade magnet alloy and/or other suitable materials. The static parameters may also include sizes of gaps between magnets in the first set of magnets **518** and sizes of gaps between magnets in the second set of magnets **520**. The static parameters of each magnet in the sets of magnets **518**, **520** may be adjusted during manufacturing to provide a predetermined amount of anti-cogging torque and/or predetermined anti-cogging torque profiles.

The magnet parameters may also include dynamic parameters, such as (i) axial displacement, (ii) radial displacement, and (iii) radial gap between the first set of magnets **518** and the second set of magnets **520**. The dynamic parameters may be set initially prior to operation of the anti-cogging apparatus and may be varied during operation of the anti-cogging apparatus. FIG. 17 illustrates dynamic axial movement of the first set of magnets **518**. Although axial and radial displacement implementations are shown separately by FIGS. 9 & 17 the axial and radial displacement implementations may be combined into a single implementation.

FIG. 17 shows a cross-sectional portion of an axial displacement system **550** that may include a first support member **552**, a second support member **554**, a shaft **556**, a first set of magnets **558**, a second set of magnets **560**, a first axial displacement mechanism **562**, and a control module **564**. The first support member **552** may be in a fixed relationship with the shaft **556** and may rotate with the shaft **556** or may be connected to the shaft **556** via one or more gears. The second support member **554** may be, for example, an engine, a torque converter, a transmission, etc. or a member attached to an engine, a torque converter, a transmission, etc. The second support member **554** may be in a fixed position. Although FIG. 17, for illustration purposes only a certain number of magnets, additional magnets may also be included in the sets of magnets **558**, **560** similar to the arrangements shown in FIGS. 15 and 18. The magnets **558**, **560** may be arranged in respective positions around the shaft **556** and on the base plates **566**, **568**.

A first base plate (or supporting ring) **566** may be attached to the first support member **552**. The first set of magnets **558** may be attached to the first support member **552** and/or the first base plate **566**. In one implementation, the first support member **552** and the first base plate **566** are formed as a single plate. A second base plate **568** may be attached to the second support member **554**. In one implementation, the second support member **554** and the second base plate **568** are formed as a single plate. The second set of magnets **560** may be attached to the second support member **554** and/or the second base plate **568**. In one implementation, the base plates **566**, **568** are not included. In another implementation, the first base plate **566** is included and the second backing plate **568** is not included. In a third implementation, the second base plate **568** is included and the first base plate **566** is not included.

Referring now also to FIG. 18, a portion of the base plates **566**, **568**, the magnets **558**, **560** and wedges **571**, **573** are shown. FIG. 18 illustrates an end view of portions of a first set of magnets and a second set of magnets and corresponding attachments. The magnets **558**, **560** may be held between (i) the respective support members **552**, **554** and/or the base plates **566**, **568**, and (ii) retaining rings **567**, **569**. The magnets **558**, **560** may be held to the respective support members **552**, **554** and/or the base plates **566**, **568** and between the base plates **566**, **568** and the retaining rings **567**, **569** via wedges **571**, **573** (further shown in FIG. 19) and respective fasteners (not shown). The fasteners may, for example, extend in and/or through holes **591** in the support members **552**, **554**, the base plates **566**, **568**, the retaining rings **567**, **569** and/or the wedges **571**, **573**. The fasteners may be used to attach the wedges **571**, **573** and/or the retaining rings **567**, **569** to the support members **552**, **554** and/or the base plates **566**, **568**.

The magnets **558**, **560** may be shaped to be held in respective recessed areas (or grooves) **575**, **577** of the base plates **566**, **568** and retaining rings and in respective recessed areas (or grooves) **579**, **581** of the wedges **571**, **573**. Gaskets and/or adhesive (designated **583**) may be used between (i) the magnets **558**, **560**, and (ii) the base plates **566**, **568** and/or the wedges **571**, **573**.

Backing plates **587** may be attached to and/or held onto backsides of the magnets **558**, **560**. The backing plates (e.g., backing plates **587**) may be held, similar to the magnets **558**, **560**, between the backing plates **566**, **568** and the retaining rings **567**, **569**. Although backing plates are shown as being used with respect to magnets **560**, backing plates may also be used with respect to the magnets **558**. In one implementation, backing plates are used on the magnets **560** and not on the magnets **558**.

The backing plates aid in increasing forces exerted between the first set of magnets **558** and the second set of magnets **560**, thereby increasing anti-cogging forces. The backing plates may include one or more magnetically conductive layers **652**, which may be laminated by one or more insulation layers **654**. The layers **652**, **654** may be stacked. The magnetically conductive layers **652** may be formed of materials that conduct magnetic flux, such as ferromagnetic materials (e.g., iron and steel). The insulation layers **654** are non-conductive layers and may each be interdisposed between two of the magnetically conductive layers **652**. The insulation layers **654** minimize and/or prevent eddy currents in the backing plates. In one implementation, the top and bottom or outer most layers of the backing plates are magnetically conductive layers **652**. In this implementation, base plates (e.g., base plates **566**, **568**), retaining rings (e.g., retaining rings **567**, **569**), and/or gaskets (e.g., gaskets **583**) may be in contact with the outer most layers (or two of the magnetically conductive layers **652**) of the backing plates. The magnets **558** and **560** may also be formed of multiple stacked layers. The layers may include magnetically conductive layers **653** and insulation layers **655**. The layers **653**, **655** may be stacked axially and may extend radially.

Characteristics of the magnets and backing plates may be set to provide certain amounts of anti-cogging torque. The characteristics may include compositions and thicknesses of each of the magnetically conductive layers and insulation layers. The characteristics may also include dimensions of the magnets and backing plates including a radial and axial thicknesses of the magnets and backing plates. The characteristics may further include: a total number of magnets and backing plates in an anti-cogging apparatus; a number of backing plates on which a first set of magnets of the

anti-cogging apparatus are attached; a number of backing plates on which a second set of magnets of the anti-cogging apparatus are attached; etc.

Referring now also to FIGS. 19A-19B, side and perspective views of an example wedge 593 is shown. The wedge 593 may be a single element and may include a magnet retaining portion 594 and a coupling portion 595. The magnet retaining portion 594 may be shaped such that ends 596 of the magnet retaining portion 594 hold or lock in place magnets (e.g., the magnets 560). The wedge 593 is an example of one of the inner wedges 573. The outer wedges 571 may be shaped differently than the inner wedges 573, as shown in FIG. 18. The coupling portion 595 has a hole 597 for attaching the wedge 593 to a base plate via a fastener.

Referring now also to FIG. 20, side and end views of an example retaining ring 598 is shown. The retaining ring 598 may replace one of the retaining rings 567, 569 of FIG. 17. The retaining ring 598 may include holes 599 for attaching the retaining ring 598 to a base plate via respective fasteners. The retaining ring 598 may have a groove 601 in which magnets and wedges may be held. The retaining ring 598 also include a center opening 603 in which a stator or a rotor may rotate.

Referring again to FIG. 17, the first support member 552, the first set of magnets 558, the first base plate 566, and the first retaining ring 567 may be collectively referred to as one of a rotor or a stator. The second support member 554, the second set of magnets 560, the second base plate 568, and the second retaining ring 569 may be collectively referred to as the other one of the rotor or the stator. The first set of magnets 558 overlap the second set of magnets 560 along the shaft 556. The first set of magnets 558 have first sides including first attachment sides (one of the first attachment sides is designated 570) and second attachment sides (one of the second attachment sides is designated 572). The first attachment sides are attached to the first base plate 566 and/or the first support member 552. The second attachment sides are opposite the first attachment sides and are attached to the first retaining ring 567. The second set of magnets 560 have second sides including third attachment sides (one of the third attachment sides is designated 574) and fourth attachment sides (one of the fourth attachment sides is designated 576). The third attachment sides are attached to the second base plate 568 and/or second support member 554. The fourth attachment sides are opposite the third attachment sides.

The first set of magnets 558 and/or the second set of magnets 560 may be axially displaced to change distances (labeled A, B, C and D) between the first and second sides (e.g., sides 570-576). Distance A is an axial distance between the first and third attachment sides (e.g., attachment sides 570, 574). Distance B is an axial distance between the second and fourth attachment sides (e.g., attachment sides 572, 576). Distance C is a distance between the first attachment side (e.g., attachment side 570) and the fourth attachment side (e.g., opposing side 576). Distance D is a distance between the second attachment side (e.g., opposing side 572) and the third attachment side (e.g., attachment side 574). The gap G3 exists between the first set of magnets 558 and the second set of magnets 560. The radial gap G3 may be adjusted, as shown in FIG. 21. The distance A may be adjusted to be within a first predetermined range and/or greater than a first predetermined distance. The distance B may be adjusted to be within a second predetermined range and/or less than a second predetermined distance. The

distance C and the distance D may each be adjusted to be within a third predetermined range and/or greater than a third predetermined distance.

The first axial displacement mechanism 562 is provided for example purposes only. The first axial displacement mechanism 562 may include a motor 580 and a screw 582 (or an actuator and/or other components). The motor 580 may turn the screw 582 to move the first support member 552, the first base plate 566, the first retaining ring 567 and the first set of magnets 558 axially and relative to the second set of magnets 560, the second base plate 568 and the second support member 554. The motor 580 and/or screw 582 may not rotate with the shaft 556 and/or the first support member 552. The screw 582 may engage with the first support member via a coupling device 584, which allows the first support member 552 to move relative to the screw 582. Although the first support member 552, the first base plate 566, the first retaining ring 567 and the first set of magnets 558 are shown as being moved axially, the second set of magnets 560, the second base plate 568, the second retaining ring 569 and the second support member 554 may also and/or alternatively be moved axially. A second axial displacement mechanism may be provided to move the second set of magnets 560, the second base plate 568, the second retaining ring 569 and the second support member 554 axially.

Although the first axial displacement mechanism 562 is shown as including a motor and a screw, the axial displacement mechanisms may include motors, actuators, screws, levers, hydraulic components, pneumatic components, electrical components, and/or other suitable components to move the sets of magnets, base plates, retaining rings, and support members axially. The sets of magnets 558, 560, base plates 566, 568, retaining rings 567, 569 and support members 552, 554 may be moved axially using electrical, pneumatic, hydraulic, and/or centrifugal forces and/or control.

The axial displacement mechanisms may be controlled by the control module 564. The control module 564 may control the axial displacement of the sets of magnets 558, 560, base plates 566, 568, the retaining rings 567, 569 and support members 552, 554 based on the magnet parameters including the static and the dynamic parameters and based on engine parameters. The engine parameters may include, for example, engine speed, throttle position, valve positions, engine load, and/or other engine parameters that affect (i) an amount of air received by an engine, and/or (ii) impedance of an exhaust of the engine. The engine parameters may include any engine parameters that affect a cogging torque the engine delivers to a crankshaft.

For example only, the first support member 552 may be held in a fixed relationship with, engage with, and/or slide along the shaft 556. A locking mechanism 590 may be incorporated to engage with the shaft. The locking mechanism may include, for example: bearings; teeth for engaging in one or more grooves or slots in the shaft 556 and/or a component attached to the shaft, clutch or pressure plates or pads for engaging with the shaft 556 and/or a component attached to the shaft, etc. The locking mechanism may also include a gearset to provide for differing rotational speeds between the shaft 556 and the first support member 552.

FIG. 21 shows a radial displacement system 600 that includes a first support member 602, a second support member 604, a shaft 606, a first set of magnets 608, a second set of magnets 610, first radial displacement mechanisms 612, and a control module 614.

The first support member 602 may be in a fixed relationship with the shaft 606, rotate with the shaft 606, and/or be

axially displaced on the shaft **606**. The second support member **604** may be in a fixed position with respect to the engine or device to which an anti-cogging torque is being applied. Although the diameters of the first and second support members **602**, **604** can be of any size, in the example shown, a diameter of the first support member **602** is smaller than a diameter of the second support member **604**. This is different than the example of FIG. 17.

The first set of magnets **608** and/or the second set of magnets **610** may replace and/or be configured similar to the first set of magnets **558** and/or the second set of magnets **560** of FIG. 15. The first support member **602** may be configured to hold the first radial displacement mechanisms **612** and/or a portion thereof.

The first radial displacement mechanisms **612** may include, for example, motors **620** and screws **622** (or actuators and/or other components) to radially displace the second set of magnets **610** towards and/or away from the first set of magnets **608**, as shown. The motors **620** may turn the screws **622** to move the second set of magnets **610** radially and relative to the first set of magnets **608**. Although the second set of magnets **610** are shown as being moved radially, the first set of magnets **608** may also and/or alternatively be moved radially. Second radial displacement mechanisms may be provided to move the first set of magnets **608** radially towards and/or away from the second set of magnets **610**.

The radial displacement mechanisms may include motors, actuators, screws, levers, hydraulic components, pneumatic components, electrical components, and/or other suitable components to move the sets of magnets **608**, **610**, radially. The sets of magnets **608**, **610** may be moved axially using electrical, pneumatic, hydraulic, and/or centrifugal forces and/or control.

The radial displacement mechanisms may be controlled by the control module **614**. The control module **614** may control the radial displacement of the sets of magnets **608**, **610** based on the magnet parameters including the static and the dynamic magnet parameters, the backing plate parameters, and the engine parameters. The radial displacement may be controlled to adjust the radial gap  $G_3$  between the first set of magnets **608** and the second set of magnets **610**. Adjustment of the radial gap  $G_3$  can provide a more linear change in anti-cogging torque than a change in radial positioning of the first and/or second sets of magnets **608**, **610**.

FIG. 22 shows an anti-cogging control system **670** that includes a control module **672**, sensors **674**, and magnet actuators **676**. The control module **672** may replace the control modules **564**, **614** of FIGS. 17 and 21. Although the control module **672** is primarily described with respect to an engine, the control module **672** may be applied to other power and/or torque producing devices, such as motors, pumps, etc. The control module **672** includes an engine parameter module **678**, a magnet parameter module **680**, a backing plate module **682**, a memory **684**, and a magnet adjustment module **686**.

The engine parameter module **678** determines and stores static and dynamic engine parameters **688**. The static (or non-varying) engine parameters may include, for example, number of cylinders, number of cogging events (or torque reversals) per revolution of a crankshaft and/or per an engine cycle, number of compression strokes per revolution of a crankshaft and/or per engine cycle, etc. The dynamic engine parameters may include, engine temperature, engine speed, engine load, engine output torque, etc. Predetermined engine output torques may be stored as an engine torque profile **690**,

which may be based on the static and/or dynamic engine parameters. The dynamic engine parameters may be determined based on signals from the sensors **674**. The sensors **674** may include an engine temperature sensor, an engine speed sensor, an engine load sensor, an engine torque sensor, etc. The control module **672** controls the magnet actuators **676** based on signals from the sensors **674** and parameters and characteristics stored in the memory **684**.

The magnet parameter module **680** determines and stores magnet parameters **692** including the static and dynamic magnet parameters, such as those described herein, in the memory **684**. The backing plate module **682** determines and stores backing plate characteristics **694**, such as those described herein, in the memory **684**.

The magnet adjustment module **686** includes an axial displacement module **690** and a radial displacement module **692** for determining respectively axial positions and radial positions of magnets in, for example, a first set of magnets (e.g., one of the first set of magnets **518**, **558**, **608** of FIGS. 15, 17, 21) and a second set of magnets (e.g., one of the second set of magnets **520**, **560**, **610** of FIGS. 15, 17, 21). The axial and radial displacement modules **690**, **692** may store axial and radial positions and/or profiles **696** of the magnets in the memory **684**. The axial and radial position and/or profiles **696** may be based on the engine parameters **688** and provide axial and radial positions relative to one or more of the engine parameters **688**. The axial and radial positions and/or profiles **696** may also be based on the engine torque profiles **690**. The axial and radial positions and/or profiles **696** may be predetermined, adjusted during operation of a corresponding engine, and/or set to satisfy anti-cogging torque profiles **698**. The anti-cogging torque profiles **698** may be stored in the memory **684**. The anti-cogging torque profiles **698** may mirror the engine torque profiles **690** in order to counteract and/or cancel, for example, negative (or reversal) torques of the engine.

The relationships between engine parameters and/or profiles **688**, **690**, magnet parameters **692**, backing plate characteristics **694**, anti-cogging torque profiles **698**, etc. may be stored as tables in the memory **684**. The control modules disclosed herein may access the tables from the memory **684** and adjust positions of magnets to adjust torque provided by the magnets, as further described below.

FIG. 23 illustrates a method of manufacturing an anti-cogging apparatus and/or system (e.g., the apparatus **500** or one of the systems **550**, **600**). Although the following tasks are primarily described with respect to the implementations of FIGS. 15-21, the tasks may be easily modified to apply to other implementations of the present disclosure. The tasks may be iteratively performed. The following tasks may be performed, for example, by a design computer and/or control module and may be performed for a certain application. Although the tasks are primarily described with respect to an engine application, the tasks may be modified to apply to other power and/or torque producing devices, such as motors, pumps, etc.

The method may begin at **700**. At **702**, engine parameters of an engine are determined. The engine parameters may include static and/or predetermined dynamic parameters and/or profiles, as described above. The engine parameters and/or engine torque profiles may be determined based on models of the engine, predetermined and stored parameters of the engine, parameters collected during operation of the engine, etc.

At **704**, if one or more backing plates are to be included, backing plate characteristics, such as those described above, may be determined. A determination of whether one or more

backing plates are to be included may be based on the magnet parameters and the engine parameters.

At **706**, the magnet parameters may be determined based on the engine parameters, predetermined engine torque profiles, predetermined engine output torque during cogging events, backing plate characteristics, etc. Although task **704** is shown as being performed prior to task **706**, task **704** may be performed prior to or while performing task **706**. For example, the backing plate characteristics may be determined based on the magnet parameters.

At **708**, axial and/or radial positions and/or profiles may be determined based on the engine parameters, engine torque profiles, backing plate characteristics, and magnet parameters. Task **708** may be performed prior to and/or while performing one or more of tasks **702-706**.

At **710**, the anti-cogging apparatus and/or system may be manufactured based on the engine parameters, engine torque profiles, backing plate characteristics, magnet parameters, and/or axial and/or radial positions and/or profiles. Task **702** may be performed subsequent to task **710**.

FIG. **24** illustrates a method of operating an anti-cogging apparatus and/or system (e.g., the apparatus **500** or one of the systems **550**, **600**). The following tasks may be performed by a control module (e.g., one of the control modules **564**, **614**, **672** of FIGS. **17**, **21** and **22**) and may be performed for a certain application. Although the tasks are primarily described with respect to an engine application, the tasks may be modified to apply to other power and/or torque producing devices, such as motors, pumps, etc. The method may begin at **720**.

At **722**, an engine parameter module (e.g., the engine parameter module **678**) may determine engine parameters and/or profiles (e.g., engine parameters and profiles **688**, **690**) of an engine.

At **724**, a backing plate module (e.g., the backing plate module **682**) may determine whether backing plates are incorporated in the anti-cogging apparatus and/or determine backing plate characteristics (e.g., backing plate characteristics **694**).

At **726**, the magnet parameter module (e.g., the magnet parameter module **680**) determines static and dynamic magnet parameters (e.g., magnet parameters **692**) and/or profiles (e.g., anti-cogging torque profiles **698**) based on the engine parameters and/or profiles.

At **728**, the magnet adjustment module (e.g., the magnet adjustment module **686**) adjusts position of magnets based on the engine parameters and/or profiles, backing plate characteristics, and/or magnet parameters and/or profiles. The positions of the magnets may be adjusted by signals one or more motors and/or actuators (e.g., one or more of the motors and/or actuators **580**, **620**). This may include determining axial and/or radial positions of one or more magnets, positions of one or more support members (e.g., one or more of the support members **512**, **514**, **552**, **554**, **602**, **604**) of the magnets, and/or positions of one or more backing plates (e.g., one or more of the backing plates **566**, **568**, **602**, **604**). The adjustments may be made to reduce and/or cancel reversal torque associated with a cogging event of the engine. Task **722** may be performed subsequent to task **728**.

The implementations disclosed herein are applicable to both 2-stroke and 4-stroke engines. As an example, twice as many magnets may be used to apply an anti-cogging torque to a shaft of a 2-stroke engine as used to apply an anti-cogging torque to a shaft of a 4-stroke engine.

FIG. **25** is a diagram of an anti-cogging system **798** illustrating an end view of a differential speed assembly **800** for an anti-cogging apparatus (or cam follower) **802**. In the

example shown, the differential speed assembly **800** includes a gear set **804** with multiple gears including a shaft gear **808**, a differential gear **810** and a cam gear (or other camming member) **812**. The differential speed assembly **800** may include components other than the stated gears to provide a speed difference between (i) a shaft **814** (e.g., a crankshaft) and (ii) the cam gear **812** and/or a cam surface **816** of the cam gear **812**. The cam surface **816** has lobes extending radially relative to an axis-of-rotation of the shaft **814**. The cam gear **812** includes inner teeth **818** that engage with teeth **820** of the differential gear **810**. The teeth **820** engage with teeth **821** of the shaft **814**. Although a certain number of gears are shown, any number of gears may be included in the differential speed assembly **800**.

The anti-cogging apparatus **802** includes one or more springs (or other biasing members) **822**, which are held between a supporting member **824** and a seat (or retainer) **826**. A rod **828** may extend in the springs **822** and the seat **826** between the support member **824** and an abutment member (or roller) **830**. The abutment member **830** rides on the cam surface **816** and provides an anti-cogging torque as described above. In one implementation, the abutment member **802** is in a fixed position relative to the shaft **814**. The shaft **814** rotates in the cam gear **812**. Although the abutment member **830** is shown as being moved in a radial direction relative to the shaft **814**, the abutment member may be configured to move in an axial direction relative to the shaft **814**.

Also, although a single anti-cogging apparatus and a single abutment member are shown with respect to implementations of certain figures, any number of anti-cogging apparatuses and/or abutment members may be utilized in any of the implementations of the figures. Furthermore, when multiple abutment member are used, the abutment members may sequentially abut against the same lobe or a plurality of lobes of a cam surface (e.g., any of the cam surfaces disclosed herein).

The differential speed assembly **800** may be utilized with any of the anti-cogging apparatuses disclosed herein. The differential speed assembly **800** may be used in an engine with any number of cylinders. In one embodiment, the differential speed assembly **800** is used in an engine with an odd number of cylinders. The differential speed assembly **800** allows the cam gear **812** to rotate at a different speed than the shaft **814**.

Tension on the one or more springs **822** may be controlled by a control module **832** using one or more actuators (actuator **834** is shown). The control module **832** may adjust an amount of tension or compression of the one or more springs **822**, for example, by adjusting a preloaded or default state of the springs **822** and/or position of the seat **826** relative to the support member **824**. The control module **832** may instruct the actuator **834** to adjust a position and/or an amount of force on the seat **826**, via pre-load elements **827** and a loading retainer **829**, which adjusts an amount of tension or compression on the springs **822**. The control module **832** may adjust tension, compression and/or load on the springs **822** based on a speed of the shaft **814**, a speed of the differential gear, and/or a speed of the cam gear **812**. The actuator **834** may include, for example, a motor, a solenoid, or other actuator suitable for adjusting load on the springs **822** and thus an amount of anti-cogging torque. The preload elements **827** may include springs, rods, elastic elements, dampening elements, and/or other suitable elements.

The number and arrangement of abutment members on anti-cogging members (e.g., the cam gear **812**), in conjunc-

tion with the differential speed assembly **800**), are such that anti-cogging inputs applied to the shaft **814** correspond to cogging inputs applied to the shaft **814**.

FIG. 26 is an end view illustrating a differential speed assembly **850** for another anti-cogging apparatus **852**. In the example shown, the differential speed assembly **850** includes a gear set **854** with multiple gears including a shaft gear **858**, a differential gear **860** and a support member **862**, which performs as another gear. The differential speed assembly **800** may include components other than the stated gears to provide a speed difference between a shaft **864** (e.g., a crankshaft) and the support member **862**. The support member **862** includes inner teeth **868** that engage with teeth **870** of the differential gear **860**. The teeth **870** engage with teeth **872** of the shaft **864**. Although a certain number of gears are shown, any number of gears may be included in the differential speed assembly **850**.

The anti-cogging apparatus **852** includes a first set of magnets **874** and a second set of magnets **876**. The first set of magnets **874** is mounted on the support member **862**. The second set of magnets **876** are mounted on a second support member **878**. The first set of magnets **874** and the second set of magnets **876** provide an anti-cogging torque as described above. In one implementation, the second set of magnets **876** are in a fixed position such that the shaft **864** rotates in the second set of magnets **876**. The first set of magnets **874** may be rotated around the shaft **864**.

The differential speed assembly **850** may be utilized with any of the anti-cogging apparatuses disclosed herein. The differential speed assembly **850** may be used in an engine with any number of cylinders. In one embodiment, the differential speed assembly **850** is used in an engine with an odd number of cylinders. The differential speed assembly **850** allows the support member **862** to rotate at a different speed than the shaft **864**. The support member **862** may be, for example, a rotor of an electrical motor.

A control module (e.g., control module **564** or control module **614**) and/or actuators may be included as described above to control positions of the first set of magnets and/or positions of the second set of magnets. Movement of the second set of magnets relative to the first set of magnets adjusts an amount of anti-cogging torque applied. This may be based on various parameters as described above including, for example, a speed of the shaft **864**.

FIGS. 27A and 27B are functional block diagrams of an anti-cogging system **898** illustrating states of a centrifugal anti-cogging apparatus (or cam follower) **900**. FIG. 27A shows the centrifugal anti-cogging apparatus **900** in an extended state. FIG. 27B shows the centrifugal anti-cogging apparatus **900** in a compressed state.

The centrifugal anti-cogging apparatus **900** includes a spring **902** (or other biasing member) that is held between a support member **904** and a seat (or retainer) **906**. A rod **908** extends through the support member **904**, the spring **902** and the seat **906**. A first end **910** of the rod **908** connects to an object **912**. The object **912** may be connected to the abutment member **916** via the rod **908** and/or other suitable coupling devices. The coupling devices connecting the object **912** to the abutment member **916** are configured to adjust the amount of anti-cogging torque based on centrifugal forces associated with rotation of the object. A second end **914** of the rod **908** connects to an abutment member **916**. The object **912** has a predetermined amount of mass and is included to provide centrifugal force.

The support member **904** may be moved radially and/or relative to a cam surface (e.g., the cam surface **818** as shown) via an actuator **920**, which may be controlled by a

control module **922** to adjust an amount of preload on the spring **902**. The actuator **920** may be connected to the support member **904** via a screw **923**.

In one implementation, the cam surface and/or corresponding camming device is connected and is in a fixed relationship with the shaft **818**. The support member **904** is not connected to the shaft and/or does not rotate. In another implementation, the cam surface and/or corresponding camming device is coupled to the shaft **818** via a differential speed assembly (e.g., the differential speed assembly of FIG. 25). In yet another implementation, the cam surface and/or corresponding camming device is not connected to the shaft **814** and and/or does not rotate. The support member **904** is connected and is in a fixed relationship with the shaft (e.g., the shaft **814** is shown). The support member **904** may rotate in a same direction as the shaft **814**, which is in an opposite direction as the cam surface **818**. The support member **904** may be connected to the shaft **904** by a differential speed assembly (e.g., the differential speed assembly in FIG. 25).

The amount of centrifugal force associated with the object **912** on the rod **908** changes with speed of the shaft **814**. As the speed of the shaft **814** increases the amount of centrifugal force increases, which increases load on the spring **902**.

FIG. 28 is a side view of another centrifugal anti-cogging apparatus **950**. The centrifugal anti-cogging apparatus **950** includes a first support member **952** with a first set of magnets **954** and a second support member **956** with a second set of magnets **958**. The first support member **952** may be stationary and thus not rotate with a shaft **960** (e.g., a crankshaft). The second support member **956** is free to slide axially on the shaft **960** and is connected to the shaft **960** via a dual-scissor arm assembly **962**.

The dual-scissor arm assembly **962** includes two pairs of scissor arms. Each pair of the scissor arms includes two arms **964**, **966**. A first end **968** of the first arm **964** is connected to an object **970** and a second end **972** of the first arm **964** is connected to an abutment member **974**. The object **970** has a predetermined amount of mass and is included to provide centrifugal force. A first end **976** of the second arm **966** is connected to the first leg **964** via a hinge **978**. A second end **980** of the second arm **966** is connected to a coupling **982**. The coupling **982** is connected and is in a fixed position relative to the shaft **960**. The abutment members **974** are held between the second support member **956** and a plate **984**. A spring **986** is held between the coupling **982** and the plate **984**. The plate **984** is free to slide axially on the shaft **960**.

A spacer **987** may be included between the plate **984** and the second support member **956**. The spacer **987** may slide on the shaft **960** and hold the plate **984** in a fixed position relative to the second support member **956**.

In operation, as the speed of the shaft **960** increases, the amount of centrifugal force associated with the objects **970** increases, forcing the objects **970** outward away from the shaft **960**, thereby moving the abutment members **974** inward towards the shaft **960**. The inward movement of the abutment members **974** causes the plate **984** and the second support member **956** to move towards the coupling **982**. This increases load on the spring **986**. The movement of the second support member **956** changes the positions of the second set of magnets **958** relative to the first set of magnets **954**. The second set of magnets **958** are moved in an axial direction relative to the first set of magnets **954**.

FIG. 29 shows an anti-cogging system **998** illustrating a side view of an anti-cogging apparatus (or cam follower) **1000**. The anti-cogging apparatus includes a cam surface **1002** of a camming device **1003** with lobes **1004** extending

in an axial direction. The anti-cogging apparatus **1000** includes a rod **1006** that extends through a support member **1008**, a spring **1010** and a seat (or retainer) **1012** and from at least the support member **1008** to an abutment member **1014**. The abutment member **1014** applies an anti-cogging torque on the cam surface **1002**. The cam surface **1002** rotates about an axis-of-rotation **1016** of a shaft **1018**. The camming device **1003** is connected to the shaft **1018**, which is coupled to a device housing **1020** (e.g., an engine block, a clutch housing, a transmission housing, or other housing). The support member **1008** may not rotate with the shaft **1018**.

Although the camming device **1003** is shown as being coupled to and rotating with the shaft **1018**, the camming device **1003** may not rotate with the shaft **1018** and the support member **1008** may alternatively be coupled to and rotate with the shaft **1018**. In one implementation, a differential speed assembly couples the camming device **1003** to the shaft **1018**. In another implementation, a differential speed assembly couples the support member **1008** to the shaft **1018**. An example of a differential speed assembly that may be used for these implementations is shown in FIG. **25**.

The anti-cogging apparatus **1000** may also include an actuator **1022** and a control module **1024**. The control module **1024** may adjust the anti-cogging torque by adjusting a position of the support member **1008** via the actuator **1022** and relative to the cam surface **1002**. This adjusts (i) an amount of load on the spring **1010**, and (ii) an amount of force applied by the abutment member **1014** on the cam surface **1002**.

The implementations disclosed herein may be utilized separately or in combination this includes combining mechanically based implementation with magnetically based implementations. For example, the implementations of FIGS. **1-4**, **25**, **27A**, **27B**, and **28-29** may be used in combination with the implementations of FIGS. **5-7**, **9**, **10A**, **10B**, **15-22** and **26**.

The foregoing description is merely illustrative in nature and is in no way intended to limit the disclosure, its application, or uses. The broad teachings of the disclosure can be implemented in a variety of forms. Therefore, while this disclosure includes particular examples, the true scope of the disclosure should not be so limited since other modifications will become apparent upon a study of the drawings, the specification, and the following claims. As used herein, the phrase at least one of A, B, and C should be construed to mean a logical (A or B or C), using a non-exclusive logical OR. It should be understood that one or more steps within a method may be executed in different order (or concurrently) without altering the principles of the present disclosure.

Although the terms first, second, third, etc. may be used herein to describe various components, magnets, backing plates, support members and/or elements, these items should not be limited by these terms. These terms may be only used to distinguish one item from another item. Terms such as "first," "second," and other numerical terms when used herein do not imply a sequence or order unless clearly indicated by the context. Thus, a first item discussed below could be termed a second item without departing from the teachings of the example implementations.

In this application, including the definitions below, the term module may be replaced with the term circuit. The term module may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC); a digital, analog, or mixed analog/digital discrete circuit; a digital, analog, or mixed analog/digital integrated circuit; a combinational

logic circuit; a field programmable gate array (FPGA); a processor (shared, dedicated, or group) that executes code; memory (shared, dedicated, or group) that stores code executed by a processor; other suitable hardware components that provide the described functionality; or a combination of some or all of the above, such as in a system-on-chip.

The term code, as used above, may include software, firmware, and/or microcode, and may refer to programs, routines, functions, classes, and/or objects. The term shared processor encompasses a single processor that executes some or all code from multiple modules. The term group processor encompasses a processor that, in combination with additional processors, executes some or all code from one or more modules. The term shared memory encompasses a single memory that stores some or all code from multiple modules. The term group memory encompasses a memory that, in combination with additional memories, stores some or all code from one or more modules. The term memory may be a subset of the term computer-readable medium. The term computer-readable medium does not encompass transitory electrical and electromagnetic signals propagating through a medium, and may therefore be considered tangible and non-transitory. Non-limiting examples of a non-transitory tangible computer readable medium include nonvolatile memory, volatile memory, magnetic storage, and optical storage.

The apparatuses and methods described in this application may be partially or fully implemented by one or more computer programs executed by one or more processors. The computer programs include processor-executable instructions that are stored on at least one non-transitory tangible computer readable medium. The computer programs may also include and/or rely on stored data.

What is claimed is:

**1.** A system comprising:

an anti-cogging apparatus comprising  
 a first support member configured to be connected to and rotate with a rotatable shaft;  
 a second support member that does not rotate and is configured not to move with the first support member;  
 a first set of magnets mounted on the first support member;  
 a second set of magnets mounted on the second support member,  
 wherein the first set of magnets magnetically interacts with the second set of magnets to provide an anti-cogging torque on the rotatable shaft;  
 a control module that controls and varies an amount of the anti-cogging torque provided to the rotatable shaft; and  
 an actuator operable to actuate one of the first set of magnets or the second set of magnets relative to the other one of the first set of magnets and the second set of magnets to vary a distance between the first set of magnets and the second set of magnets,  
 wherein the control module is operable to control the actuator to control the distance between the first set of magnets and the second set of magnets to thereby vary the amount of the anti-cogging torque provided to the rotatable shaft.

**2.** The system of claim **1**, wherein the first support member is configured to be (i) directly connected to and rotate with the rotatable shaft, or (ii) connected through a gearset or speed varying device to the rotatable shaft.

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3. The system of claim 1, wherein:  
the first set of magnets having at least one magnet  
mounted on the first support member in a first polarity  
configuration; and  
the second set of magnets having at least one magnet 5  
mounted on the second support member in a second  
polarity configuration.
4. The system of claim 1, wherein the rotatable shaft is a  
crankshaft of an engine.
5. The system of claim 1, wherein a number and arrange- 10  
ment of the first set of magnets and the second sets of  
magnets are such that the anti-cogging torque acting on the  
rotatable shaft corresponds to and opposes cogging inputs  
acting on the rotatable shaft.
6. The system of claim 1, wherein: 15  
the first support member is configured to be connected  
through a gearset to the rotatable shaft; and  
the first set of magnets, the second sets of magnets and the  
gearset are configured such that the anti-cogging torque  
acting on the rotatable shaft corresponds to and opposes 20  
cogging inputs acting on the rotatable shaft.
7. The system of claim 1, further comprising a plurality of  
backing plates respectively attached to the first set of mag- 25  
nets, wherein each of the plurality of backing plates com-  
prises:  
a plurality of magnetically conductive layers; and  
an insulation layer disposed between the plurality of  
magnetically conductive layers of the corresponding  
backing plate.
8. The system of claim 1, further comprising a plurality of 30  
backing plates respectively attached to the second set of  
magnets, wherein each of the plurality of backing plates  
comprises:  
at least one magnetically conductive layer; and  
at least one insulation layer. 35
9. The system of claim 1, further comprising a plurality of  
backing plates respectively attached to the second set of  
magnets, wherein each of the plurality of backing plates  
comprises: 40  
a plurality of magnetically conductive layers; and  
an insulation layer disposed between the plurality of  
magnetically conductive layers of the corresponding  
backing plate.
10. The system of claim 1, wherein at least one of the  
magnets in the first set of magnets or in the second set of 45  
magnets includes a ferromagnetic material.
11. The system of claim 1, further comprising a spring  
positioned to return the first support member to a predeter-  
mined original position, wherein: 50  
the actuator is connected to the first support member;  
the actuator includes at least one object having a mass and  
affixed to at least one arm pivotably attached to the  
rotatable shaft; and  
centrifugal force displaces the object radially outward 55  
from the rotating shaft and causes the first set of  
magnets to displace axially along the rotatable shaft  
relative to the second set of magnets against a force of  
the spring.
12. The system of claim 1, wherein: 60  
the actuator is connected to the first support member or to  
the second support member; and  
the control module is configured to, via the actuator (i)  
axially displace the first set of magnets along the  
rotatable shaft and relative to the second set of magnets,  
or (ii) axially displace the second set of magnets along 65  
the rotatable shaft and relative to the first set of mag-  
nets.

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13. An anti-cogging apparatus comprising:  
a first support member configured to be connected to and  
rotate with a rotatable shaft;  
a second support member that does not rotate and is  
configured not to move with the first support member;  
a first set of magnets mounted on the first support mem-  
ber;  
a second set of magnets mounted on the second support  
member,  
wherein the first set of magnets magnetically interacts  
with the second set of magnets to provide an anti-  
cogging torque on the rotatable shaft;  
a number of magnets included in the first set of magnets  
is a multiple of at least one of (i) a number of cylinders  
in an engine, and (ii) a number of cogging events per  
an engine cycle, wherein the first set of magnets  
includes one or more magnets; and  
a number of magnets included in the second set of  
magnets is a multiple of at least one of (i) the number  
of cylinders in the engine, and (ii) the number of  
cogging events per an engine cycle, wherein the second  
set of magnets includes one or more magnets, and  
wherein anti-cogging events provided by the first set of  
magnets and the second set of magnets correspond  
respectively and oppose cogging events of the rotatable  
shaft.
14. A system comprising:  
an anti-cogging apparatus comprising  
a first support member configured to be connected to  
and rotate with a rotatable shaft,  
a second support member that does not rotate and is  
configured not to move with the first support mem-  
ber,  
a first set of magnets mounted on the first support  
member, and  
a second set of magnets mounted on the second support  
member,  
wherein the first set of magnets magnetically interacts  
with the second set of magnets to provide an anti-  
cogging torque on the rotatable shaft;  
a first actuator connected to a first one or more magnets  
in the first set of magnets or to a first one or more  
magnets in the second set of magnets; and  
a control module configured to, via the first actuator, (i)  
displace the first one or more magnets in the first set of  
magnets radially and relative to a second one or more  
magnets in the second set of magnets, or (ii) displace  
the second set of magnets radially and relative to the  
first set of magnets.
15. The system of claim 14, further comprising a second  
actuator, 5  
wherein the control module is configured to, via the  
second actuator, (i) axially displace the first set of  
magnets along the rotatable shaft and relative to the  
second set of magnets, or (ii) axially displace the  
second set of magnets along the rotatable shaft and  
relative to the first set of magnets.
16. A system comprising:  
a first support member configured to be connected to and  
rotate with a rotatable shaft;  
a second support member that does not rotate and is  
configured not to move with the first support member;  
a first set of magnets having at least one magnet mounted  
on the first support member; and  
a second set of magnets having at least one magnet  
mounted on the second support member,

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wherein the first set of magnets magnetically interacts with the second set of magnets to provide an anti-cogging torque on the rotatable shaft; and a first actuator configured to axially displace one or more magnets in the first set of magnets or in the second set of magnets to adjust the anti-cogging torque applied to the rotatable shaft.

17. The system of claim 16, wherein the first support member is configured to be (i) directly connected to and rotate with the rotatable shaft, or (ii) connected through a gearset or speed varying device to the rotatable shaft.

18. The system of claim 16, wherein a number and arrangement of the first set of magnets and the second sets of magnets are such that the anti-cogging torque acting on the rotatable shaft corresponds to and opposes cogging inputs acting on the rotatable shaft.

19. The system of claim 16, wherein:  
the first support member is configured to be connected through a gearset to the rotatable shaft; and  
the first set of magnets, the second sets of magnets and the gearset are configured such that the anti-cogging torque acting on the rotatable shaft corresponds to and opposes cogging inputs acting on the rotatable shaft.

20. The system of claim 16, wherein the first actuator (i) axially displaces the first set of magnets along the rotatable shaft and relative to the second set of magnets, or (ii) axially displaces the second set of magnets along the rotatable shaft and relative to the first set of magnets.

21. The system of claim 16, further comprising a second actuator configured to (i) displace at least one of the first set of magnets radially and relative to the second set of magnets, or (ii) at least one of the second set of magnets radially and relative to the first set of magnets.

22. The system of claim 16, further comprising a plurality of backing plates respectively attached to the first set of magnets, wherein each of the plurality of backing plates comprises:  
at least one magnetically conductive layer; and  
at least one insulation layer.

23. The system of claim 16, further comprising a plurality of backing plates respectively attached to the first set of magnets, wherein each of the plurality of backing plates comprises:  
a plurality of magnetically conductive layers; and  
an insulation layer disposed between the plurality of magnetically conductive layers of the corresponding backing plate.

24. The system of claim 16, further comprising a plurality of backing plates respectively attached to the second set of magnets, wherein each of the plurality of backing plates comprises:  
at least one magnetically conductive layer; and  
at least one insulation layer.

25. The system of claim 16, further comprising a plurality of backing plates respectively attached to the second set of magnets, wherein each of the plurality of backing plates comprises:  
a plurality of magnetically conductive layers; and  
an insulation layer disposed between the plurality of magnetically conductive layers of the corresponding backing plate.

26. The system of claim 16, further comprising a control module configured to control the first actuator to:  
maintain an overlap between the first set of magnets and the second set of magnets in an axial direction;  
adjust an axial position of the first set of magnets relative to the second set of magnets; and

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adjust a distance between (i) attachment sides of the first set of magnets, and (ii) attachment sides of the second set of magnets to be within a predetermined range and greater than a minimum predetermined distance.

27. The system of claim 16, wherein:  
the first set of magnets is mounted on the first support member in an alternating polarity configuration or a non-alternating polarity configuration; and  
the second set of magnets is mounted on the second support member in an alternating polarity configuration or a non-alternating polarity configuration.

28. An anti-cogging apparatus comprising:  
a first support member configured to be connected to and rotate with a rotatable shaft;  
a second support member configured not to move with the first support member;  
a first magnet mounted on the first support member;  
a second magnet mounted on the second support member, wherein the first magnet magnetically interacts with the second magnet to provide an anti-cogging torque on the rotatable shaft; and  
a first backing plate attached either to the first magnet or to the second magnet,  
wherein the first backing plate comprises  
at least one magnetically conductive layer, and  
at least one insulation layer, and  
wherein the first backing plate increases forces exerted between the first magnet and the second magnet and the anti-cogging torque.

29. The anti-cogging apparatus of claim 28, further comprising a plurality of backing plates respectively attached to the first magnet, wherein:  
each of the plurality of backing plates comprises  
a magnetically conductive layer, and  
an insulation layer; and  
the plurality of backing plates comprise the first backing plate.

30. The anti-cogging apparatus of claim 28, wherein the anti-cogging torque counteracts a cogging torque of an engine.

31. The anti-cogging apparatus of claim 28, wherein each of the at least one magnetically conductive layer is laminated by a corresponding one of the at least one insulation layer.

32. The anti-cogging apparatus of claim 28, wherein the at least one insulation layer prevents eddy currents in the first backing plate.

33. The anti-cogging apparatus of claim 28, wherein the first backing plate is directly connected to the first magnet or the second magnet.

34. The anti-cogging apparatus of claim 28, wherein an amount of the anti-cogging torque is based on characteristics of the first magnet, the second magnet and the first backing plate.

35. The anti-cogging apparatus of claim 34, wherein the characteristics of the first magnet, the second magnet and the first backing plate comprise: compositions and thicknesses of the at least one magnetically conductive layer and the at least one insulation layer; dimensions of the first magnet, the second magnet and the first backing plate; and a total number of magnets and backing plates in the anti-cogging apparatus.

36. The anti-cogging apparatus of claim 28, wherein the first support member is configured to be (i) directly connected to and rotate with the rotatable shaft, or (ii) connected through a gearset or speed varying device to the rotatable shaft.

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**37.** The anti-cogging apparatus of claim **28**, wherein:  
the first backing plate comprises a plurality of magnetically  
conductive layers including the at least one magnetically  
conductive layer;

the at least one insulation layer is disposed between the  
plurality of magnetically conductive layers; and  
the plurality of magnetically conductive layers and the at  
least one insulation layer are stacked.

**38.** The anti-cogging apparatus of claim **28**, further comprising:

a first set of magnets mounted on the first support member,  
wherein the first set of magnets includes the first magnet,

a first plurality of backing plates comprising the first  
backing plate, wherein the first plurality of backing plates  
are attached respectively to magnets in the first set of magnets;

a second set of magnets mounted on the second support  
member, wherein the second set of magnets include the  
second magnet; and

a second plurality of backing plates attached respectively  
to the second set of magnets,

wherein each of the first plurality of backing plates and  
the second plurality of backing plates comprises

a plurality of magnetically conductive layers configured  
to conduct magnetic flux generated by the first set of  
magnets or the second set of magnets, and

a plurality of insulating layers, wherein each of the  
plurality of insulating layers is interdisposed between two  
of the plurality of magnetically conductive layers.

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**39.** A system comprising:

the anti-cogging apparatus of claim **38**;

a first actuator configured to axially displace the first set  
of magnets or the second set of magnets along the shaft;

a second actuator configured to radially displace at least  
one magnet in the first set of magnets or the second set  
of magnets; and

a control module configured to control the first actuator  
and the second actuator to vary the anti-cogging torque  
provided to the rotatable shaft.

**40.** The system of claim **1**, wherein:

the first set of magnets is mounted on the first support  
member in either a first alternating polarity configuration  
or a first non-alternating polarity configuration; and

the second set of magnets is mounted on the second  
support member in either a second alternating polarity  
configuration or a second non-alternating polarity  
configuration.

**41.** The anti-cogging apparatus of claim **38**, wherein:

the first set of magnets is mounted on the first support  
member in an alternating polarity configuration or a  
non-alternating polarity configuration; and

the second set of magnets is mounted on the second  
support member in an alternating polarity configuration  
or a non-alternating polarity configuration.

**42.** The anti-cogging apparatus of claim **37**, the plurality  
of magnetically conductive layers and the at least one  
insulation layer are stacked axially and extend radially.

\* \* \* \* \*